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## EUROPEAN PATENT APPLICATION

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• Fuller, Timothy J.  
Pittsford, NY 14534-4023 (US)

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(74) Representative: Pike, Christopher Gerard et al  
Rank Xerox Ltd.,  
Patent Department,  
Parkway  
Marlow, Buckinghamshire SL7 1YL (GB)

(71) Applicant: XEROX CORPORATION  
Rochester New York 14644 (US)

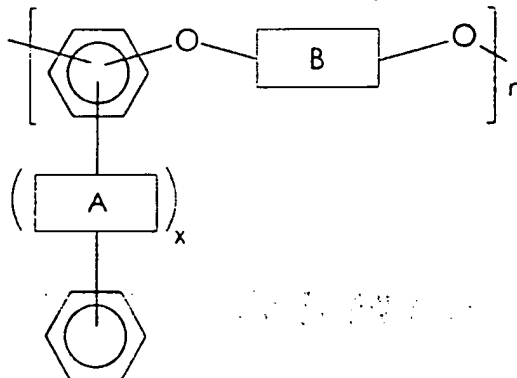
(72) Inventors:  
• Narang, Ram S.  
Fairport, NY 14450 (US)

(54) High performance curable polymers and processes for the preparation thereof

(57) Disclosed is a composition which comprises a polymer containing at least some monomer repeat units with photosensitivity-imparting substituents which enable crosslinking or chain extension of the polymer upon exposure to actinic radiation, said polymer being of the formula



or



wherein x is an integer of 0 or 1, A and B are specified groups and n is an integer representing the number of repeating monomer units, wherein said photosensitivity-imparting substituents are allyl ether groups, epoxy groups, or mixtures thereof. Also disclosed are a process for preparing a thermal ink jet printhead containing the aforementioned polymers

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and processes for preparing the aforementioned polymers.



## Description

The present invention is directed to curable polymeric materials. More specifically, the present invention is directed to high performance polymers with photosensitivity-imparting groups, processes for the preparation thereof, and improved photoresist and improved thermal ink jet printheads containing these materials.

In microelectronics applications, there is a great need for low dielectric constant, high glass transition temperature, thermally stable, photopatternable polymers for use as interlayer dielectric layers and as passivation layers which protect microelectronic circuitry. Poly(imides) are widely used to satisfy these needs; these materials, however, have disadvantageous characteristics such as relatively high water sorption and hydrolytic instability. There is thus a need for high performance polymers which can be effectively photopatterned and developed at high resolution.

One particular application for such materials is the fabrication of ink jet printheads.

Other microelectronics applications include printed circuit boards, lithographic printing processes, and interlayer dielectrics.

Copending application U.S. Serial No. 08/705,375 discloses an improved composition comprising a defined photopatternable polymer containing at least some monomer repeat units with photosensitivity-imparting substituents.

Copending application U.S. Serial No. 08/705,365 discloses a composition which comprises (a) a defined polymer containing at least some monomer repeat units with photosensitivity-imparting substituents which enable crosslinking or chain extension of the polymer upon exposure to actinic radiation; (b) at least one member selected from the group consisting of photoinitiators and sensitizers; and (c) an optional solvent.

Copending application U.S. Serial No. 08/705,488 discloses a composition comprising a polymer with a weight average molecular weight of from about 1,000 to about 65,000, said polymer containing at least some monomer repeat units with a first, photosensitivity-imparting substituent which enables crosslinking or chain extension of the polymer upon exposure to actinic radiation, said polymer also containing a second, thermal sensitivity-imparting substituent which enables further polymerization of the polymer upon exposure to temperatures of about 140°C and higher.

Copending application U.S. Serial No. 08/697,761 discloses a process which comprises reacting a defined polymer with (i) a formaldehyde source, and (ii) an unsaturated acid in the presence of an acid catalyst, thereby forming a curable polymer with unsaturated ester groups.

Copending application U.S. Serial No. 08/705,463 discloses a process which comprises reacting a defined polymer with an acetyl halide and dimethoxymethane in the presence of a halogen-containing Lewis acid catalyst and methanol, thereby forming a haloalkylated polymer. In a specific embodiment, the haloalkylated polymer is then reacted further to replace at least some of the haloalkyl groups with photosensitivity-imparting groups.

Copending application U.S. Serial No. 08/705,479 discloses a process which comprises reacting a haloalkylated aromatic polymer with a material selected from the group consisting of unsaturated ester salts, alkoxide salts, alkyl-carboxylate salts, and mixtures thereof, thereby forming a curable polymer having functional groups corresponding to the selected salt.

Copending application U.S. Serial No. 08/705,376 discloses a composition which comprises a mixture of (A) a first component comprising a polymer, at least some of the monomer repeat units of which have at least one photosensitivity-imparting group thereon, and (B) a second component which comprises either (1) a polymer having a second degree of photosensitivity-imparting group substitution or (2) a reactive diluent having at least one photosensitivity-imparting group per molecule and having a fourth degree of photosensitivity-imparting group substitution.

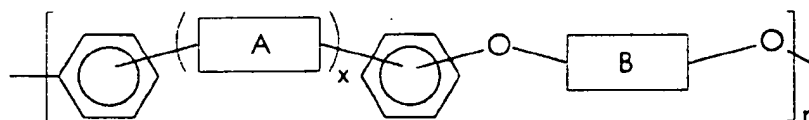
Copending application U.S. Serial No. 08/697,760 discloses a composition which comprises a defined polymer containing at least some monomer repeat units with water-solubility-imparting substituents and at least some monomer repeat units with photosensitivity-imparting substituents which enable crosslinking or chain extension of the polymer upon exposure to actinic radiation.

While known compositions and processes are suitable for their intended purposes, a need remains for improved materials suitable for microelectronics applications. A need also remains for improved ink jet printheads. Further, there is a need for photopatternable polymeric materials which are heat stable, electrically insulating, and mechanically robust. Additionally, there is a need for photopatternable polymeric materials which are chemically inert with respect to the materials that might be employed in ink jet ink compositions. There is also a need for photopatternable polymeric materials which exhibit low shrinkage during post-cure steps in microelectronic device fabrication processes. In addition, a need remains for photopatternable polymeric materials which exhibit a relatively long shelf life. Further, there is a need for photopatternable polymeric materials which can be patterned with relatively low photo-exposure energies. Additionally, a need remains for photopatternable polymeric materials which, in the cured form, exhibit good solvent resistance. There is also a need for photopatternable polymeric materials which, when applied to microelectronic devices by spin casting techniques and cured, exhibit reduced edge bead and no apparent lips and dips. In addition, a need remains for photopatternable polymeric materials which allow the production of high aspect ratio features at very high resolutions. Further, a need remains for photopatternable polymeric materials which function as a barrier layer and which may also be able to function as an adhesive layer in thermal ink jet printheads, possibly eliminating the need

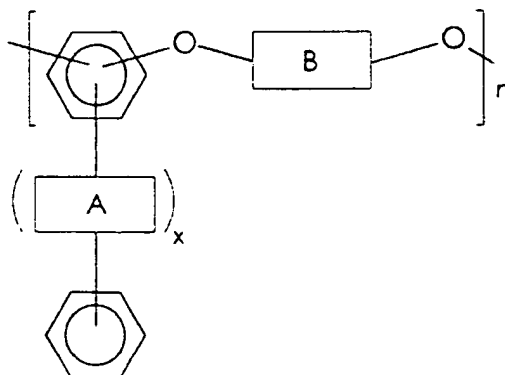


for an additional adhesive layer to bond the heater plate to the channel plate. Additionally, there is a need for photopatternable polymeric materials which exhibit improved adhesion to the heater plate of a thermal ink jet printhead. In addition, there remains a need for photopatternable polymeric materials which have relatively low dielectric constants. Further, there is a need for photopatternable polymeric materials which exhibit reduced water sorption. Additionally, a need remains for photopatternable polymeric materials which exhibit improved hydrolytic stability, especially upon exposure to alkaline solutions. A need also remains for photopatternable polymeric materials which are stable at high temperatures, typically greater than about 150°C. There is also a need for photopatternable polymeric materials which either have high glass transition temperatures or are sufficiently crosslinked that there are no low temperature phase transitions subsequent to photoexposure. Further, a need remains for photopatternable polymeric materials with low coefficients of thermal expansion. There is a need for polymers which are thermally stable, patternable as thick films of about 30 microns or more, exhibit low  $T_g$  prior to photoexposure, have low dielectric constants, are low in water absorption, have low coefficients of expansion, have desirable mechanical and adhesive characteristics, and are generally desirable for interlayer dielectric applications, including those at high temperatures, which are also photopatternable. There is also a need for photoresist compositions with good to excellent processing characteristics.

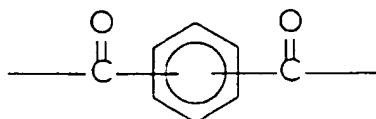
According to one aspect of the present invention, there is provided a composition which comprises a polymer containing at least some monomer repeat units with photosensitivity-imparting substituents which enable crosslinking or chain extension of the polymer upon exposure to actinic radiation, said polymer being of the formula



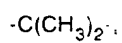
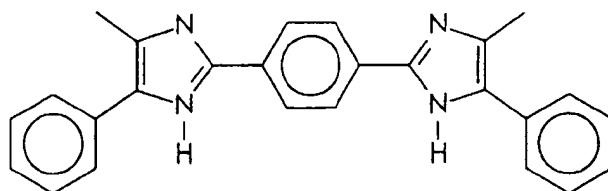
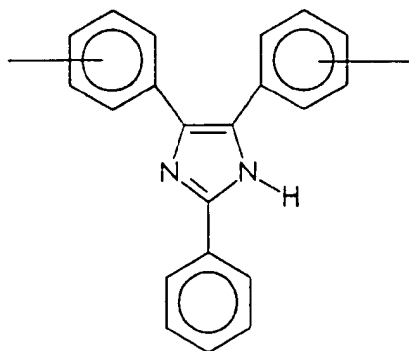
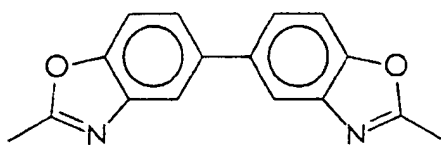
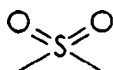
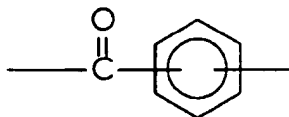
or



wherein x is an integer of 0 or 1, A is



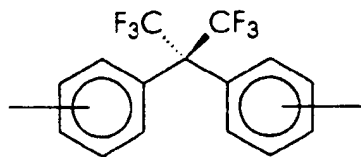




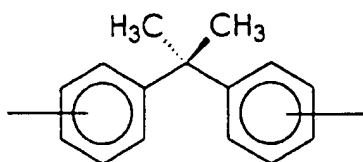


or mixtures thereof, B is

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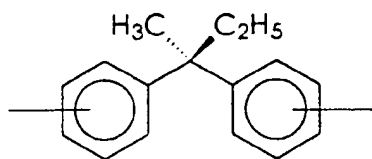


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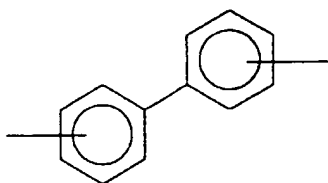
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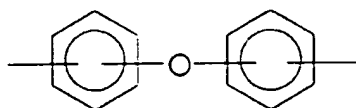
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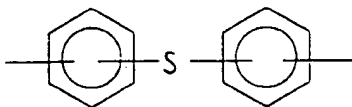


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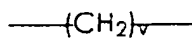
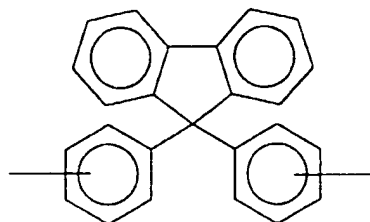
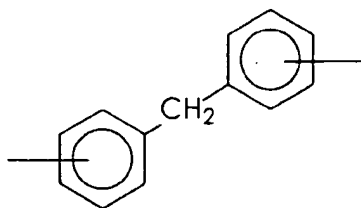
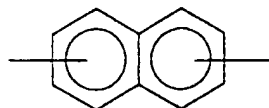
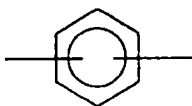
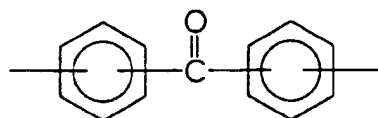
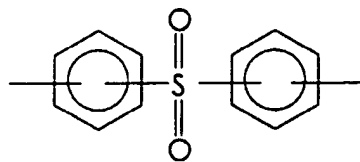
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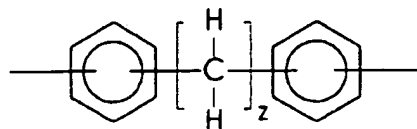




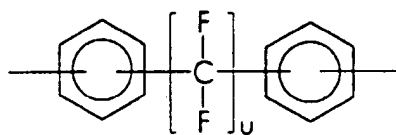
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wherein v is an integer of from 1 to about 20.

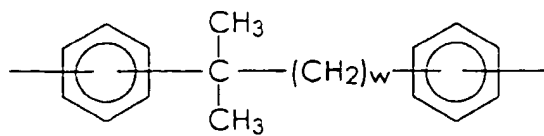
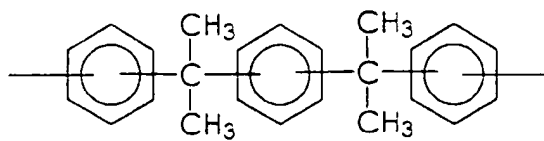
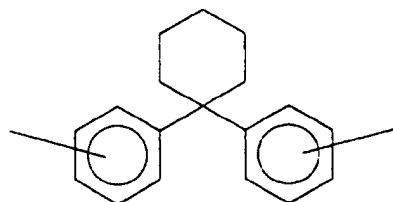
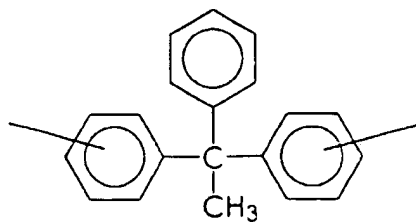




wherein z is an integer of from 2 to about 20,

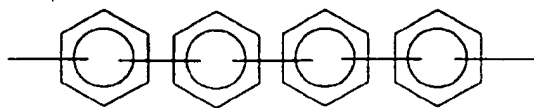
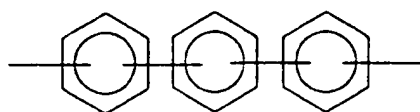
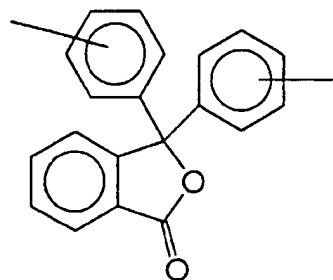
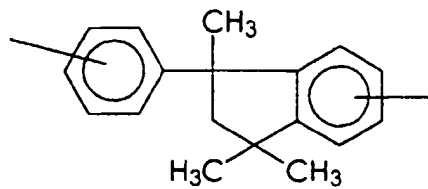


wherein u is an integer of from 1 to about 20,



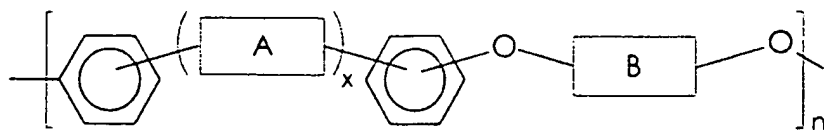
wherein w is an integer of from 1 to about 20,



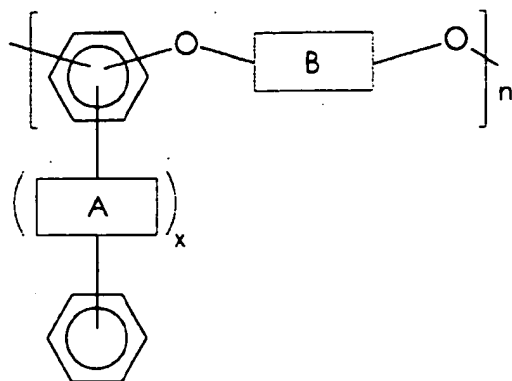


or mixtures thereof, and  $n$  is an integer representing the number of repeating monomer units, wherein said photosensitivity-imparting substituents are allyl ether groups, epoxy groups, or mixtures thereof.

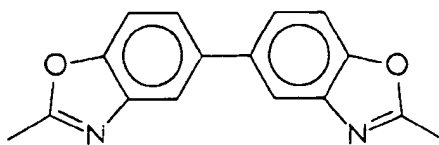
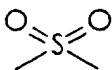
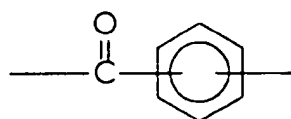
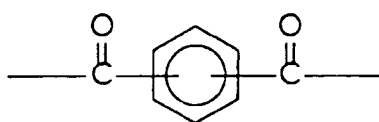
According to a process of the present invention, there is provided a process which comprises reacting a polymer containing at least some monomer repeat units with halocalkyl substituents thereon and of the formula



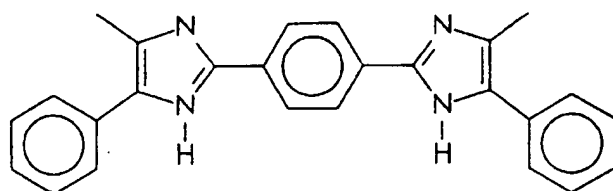
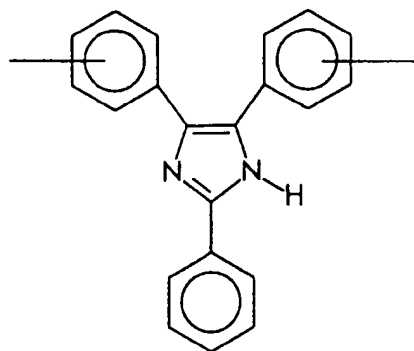




wherein x is an integer of 0 or 1, A is



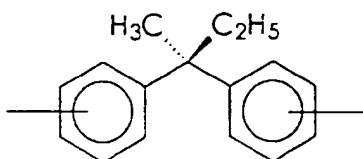
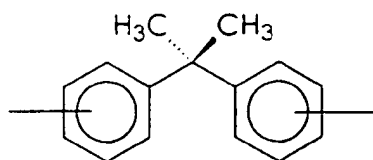
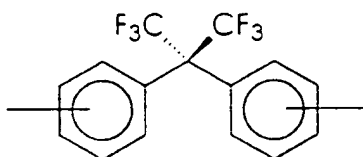




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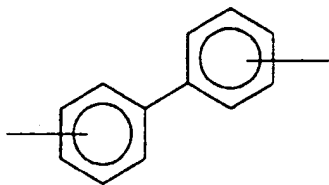
-C(CH<sub>3</sub>)<sub>2</sub>-,

or mixtures thereof, B is

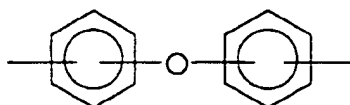




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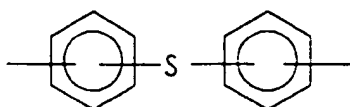


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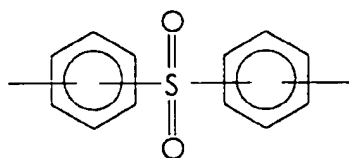
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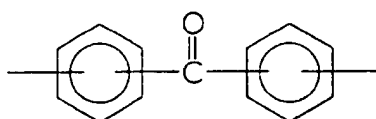


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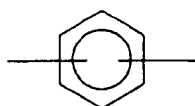


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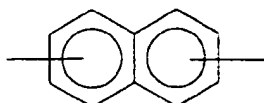


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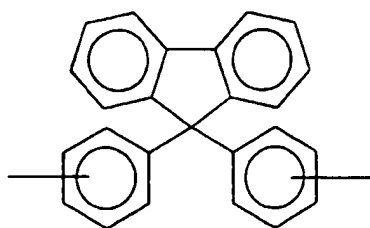
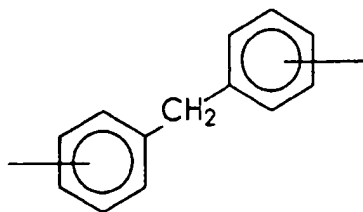


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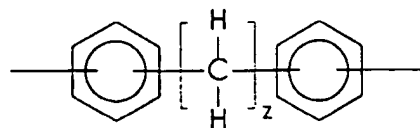


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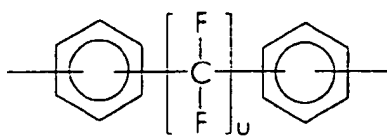


wherein v is an integer of from 1 to about 20,



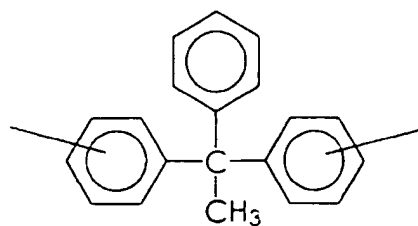
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wherein z is an integer of from 2 to about 20,

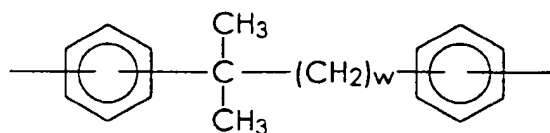
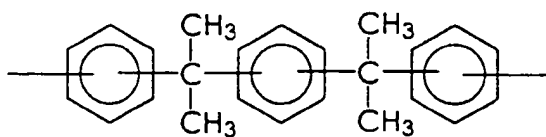
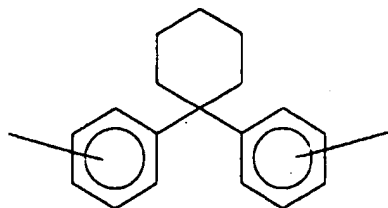


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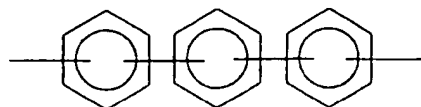
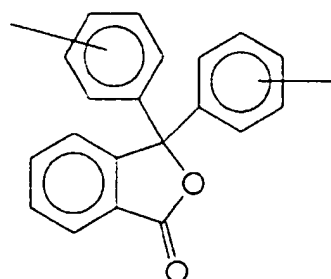
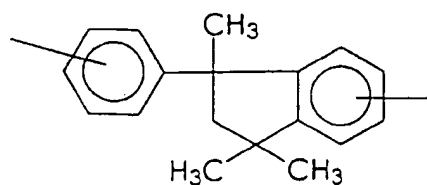
wherein u is an integer of from 1 to about 20,



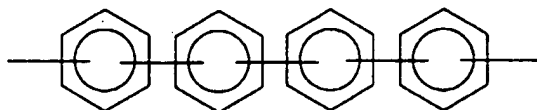




wherein w is an integer of from 1 to about 20,







or mixtures thereof, and  $n$  is an integer representing the number of repeating monomer units, with a functional group providing salt selected from the group consisting of an allyl alcohol salt, and an epoxy-group containing salt, thereby forming a photopatternable polymer with functional groups corresponding to the selected salt.

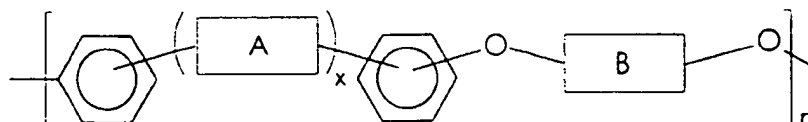
According to another aspect of the present invention, there is provided a process for making an ink jet printhead comprising the steps of: (a) depositing a layer comprising a polymer-containing composition onto a lower substrate in which one surface thereof has an array of heating elements and addressing electrodes having terminal ends formed thereon; (b) exposing the layer to actinic radiation in an imagewise pattern such that the polymer in exposed areas becomes crosslinked or chain extended and the polymer in unexposed areas does not become crosslinked or chain extended, wherein the unexposed areas correspond to areas of the lower substrate having thereon the heating elements and the terminal ends of the addressing electrodes; (c) removing the polymer from the unexposed areas, thereby forming recesses in the layer, said recesses exposing the heating elements and the terminal ends of the addressing electrodes; (d) providing an upper substrate with a set of parallel grooves for subsequent use as ink channels and a recess for subsequent use as a manifold, the grooves being open at one end for serving as droplet emitting nozzles; and (e) aligning, mating, and bonding the upper and lower substrates together to form a printhead with the grooves in the upper substrate being aligned with the heating elements in the lower substrate to form droplet emitting nozzles, thereby forming an ink jet printhead.

Figure 1 is an enlarged schematic isometric view of an example of a printhead mounted on a daughter board showing the droplet emitting nozzles.

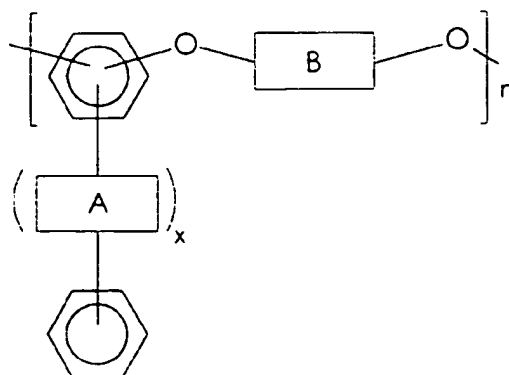
Figure 2 is an enlarged cross-sectional view of Figure 1 as viewed along the line 2-2 thereof and showing the electrode passivation and ink flow path between the manifold and the ink channels.

Figure 3 is an enlarged cross-sectional view of an alternate embodiment of the printhead in Figure 1 as viewed along the line 2-2 thereof.

The present invention is directed to curable polymers. The curable polymers of the present invention are prepared from polymers of the following formula:

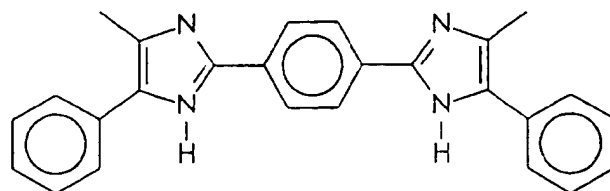
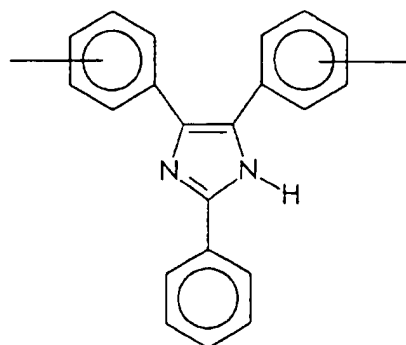
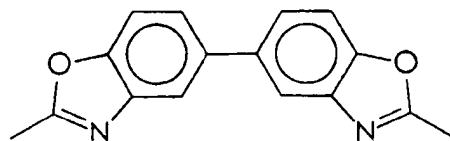
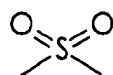
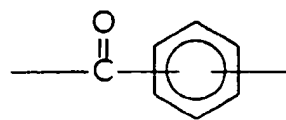
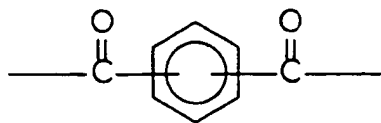


or

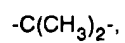


wherein  $x$  is an integer of 0 or 1,  $A$  is

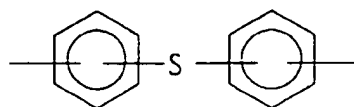
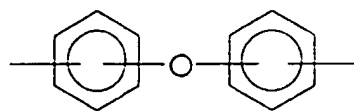
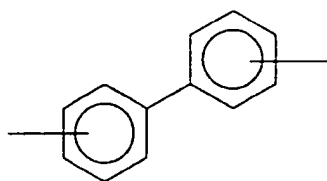
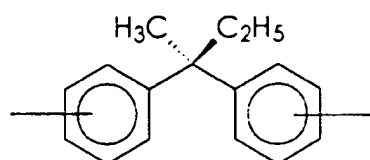
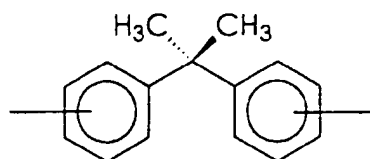
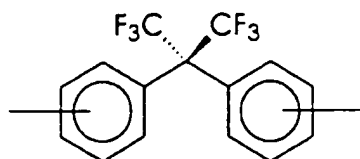




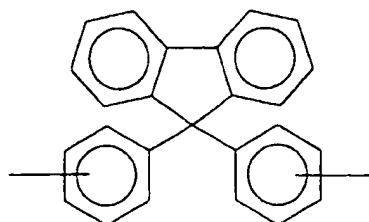
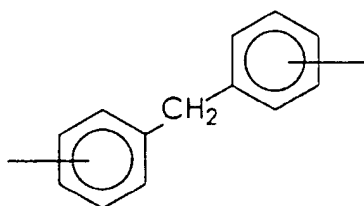
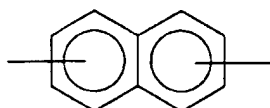
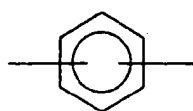
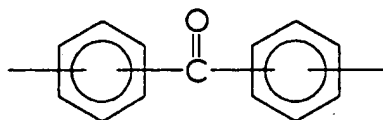
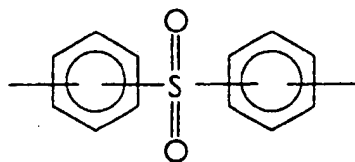




or mixtures thereof, B is



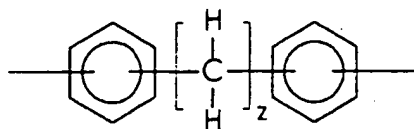




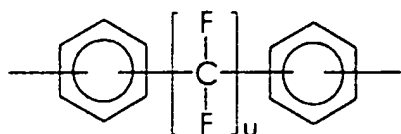
40

wherein v is an integer of from 1 to about 20, and preferably from 1 to about 10,

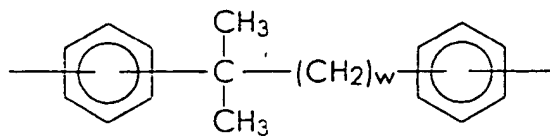
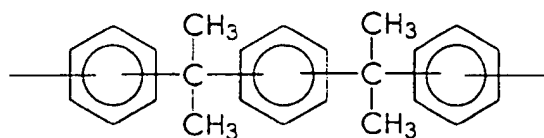
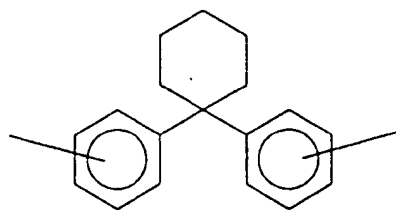
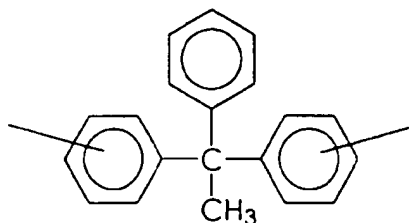




wherein z is an integer of from 2 to about 20, and preferably from 2 to about 10,

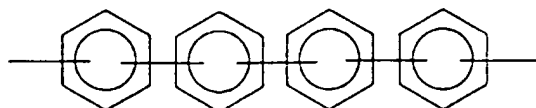
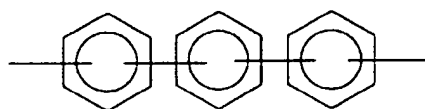
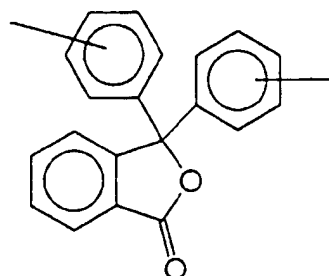
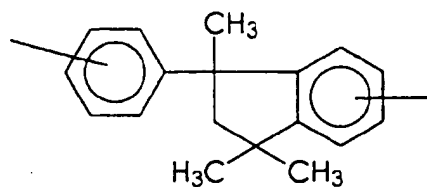


wherein u is an integer of from 1 to about 20, and preferably from 1 to about 10,



wherein w is an integer of from 1 to about 20, and preferably from 1 to about 10,





other similar bisphenol derivatives, or mixtures thereof, and  $n$  is an integer representing the number of repeating monomer units. The value of  $n$  is such that the weight average molecular weight of the material typically is from about 1,000 to about 100,000, preferably from about 1,000 to about 65,000, more preferably from about 1,000 to about 40,000, and even more preferably from about 3,000 to about 25,000, although the weight average molecular weight can be outside these ranges. Preferably,  $n$  is an integer of from about 2 to about 70, more preferably from about 5 to about 70, and even more preferably from about 8 to about 50, although the value of  $n$  can be outside these ranges. The phenyl groups and the A and/or B groups may also be substituted, although the presence of two or more substituents on the B group ortho to the oxygen groups can render substitution difficult. Substituents can be present on the polymer either prior to or subsequent to the placement of photosensitivity-imparting functional groups thereon. Substituents can also be placed on the polymer during the process of placement of photosensitivity-imparting functional groups thereon. Examples of suitable substituents include (but are not limited to) alkyl groups, including saturated, unsaturated, and cyclic alkyl groups, preferably with from 1 to about 6 carbon atoms, substituted alkyl groups, including saturated, unsaturated, and cyclic substituted alkyl groups, preferably with from 1 to about 6 carbon atoms, aryl groups, preferably with from 6 to about 24 carbon atoms, substituted aryl groups, preferably with from 6 to about 24 carbon atoms, arylalkyl groups, preferably with from 7 to about 30 carbon atoms, substituted arylalkyl groups, preferably with from 7 to about 30 carbon atoms, alkoxy groups, preferably with from 1 to about 6 carbon atoms, substituted alkoxy groups, preferably with from 1 to about 6 carbon atoms, aryloxy groups, preferably with from 6 to about 24 carbon atoms, substituted aryloxy groups, preferably with from 6 to about 24 carbon atoms, arylalkyloxy groups, preferably with from 7 to about 30 carbon atoms, substituted arylalkyloxy groups, preferably with from 7 to about 30 carbon atoms, hydroxy groups, amine groups, imine groups, ammonium groups, pyridine groups, pyridinium groups, ether groups, ester groups, amide groups, carbonyl groups, thiocarbonyl groups, sulfate groups, sulfonate groups, sulfide groups, sulfoxide groups, phos-



phine groups, phosphonium groups, phosphate groups, mercapto groups, nitroso groups, sulfone groups, acyl groups, acid anhydride groups, azide groups, and the like, wherein the substituents on the substituted alkyl groups, substituted aryl groups, substituted arylalkyl groups, substituted alkoxy groups, substituted aryloxy groups, and substituted arylalkyloxy groups can be (but are not limited to) hydroxy groups, amine groups, imine groups, ammonium groups, pyridine groups, pyridinium groups, ether groups, aldehyde groups, ketone groups, ester groups, amide groups, carboxylic acid groups, carbonyl groups, thiocarbonyl groups, sulfate groups, sulfonate groups, sulfide groups, sulfoxide groups, phosphine groups, phosphonium groups, phosphate groups, cyano groups, nitrile groups, mercapto groups, nitroso groups, halogen atoms, nitro groups, sulfone groups, acyl groups, acid anhydride groups, azide groups, mixtures thereof, and the like, wherein two or more substituents can be joined together to form a ring. Processes for the preparation of these materials are known, and disclosed in, for example, P. M. Hergenrother, J. *Macromol. Sci. Rev. Macromol. Chem.*, **C19** (1), 1-34 (1980); P. M. Hergenrother, B. J. Jensen, and S. J. Havens, *Polymer*, **29**, 358 (1988); B. J. Jensen and P. M. Hergenrother, "High Performance Polymers," Vol. 1, No. 1 page 31 (1989), "Effect of Molecular Weight on Poly(arylene ether ketone) Properties"; V. Percec and B. C. Auman, *Makromol. Chem.* **185**, 2319 (1984); "High Molecular Weight Polymers by Nickel Coupling of Aryl Polychlorides," I. Colon, G. T. Kwiatkowski, J. *of Polymer Science, Part A, Polymer Chemistry*, **28**, 367 (1990); M. Ueda and T. Ito, *Polymer J.*, **23** (4), 297 (1991); "Ethynyl-Terminated Polyarylates: Synthesis and Characterization," S. J. Havens and P. M. Hergenrother, J. *of Polymer Science: Polymer Chemistry Edition*, **22**, 3011 (1984); "Ethynyl-Terminated Polysulfones: Synthesis and Characterization," P. M. Hergenrother, J. *of Polymer Science: Polymer Chemistry Edition*, **20**, 3131 (1982); K. E. Dukes, M. D. Forbes, A. S. Jeevarajan, A. M. Belu, J. M. DeDimone, R. W. Linton, and V. V. Sheares, *Macromolecules*, **29**, 3081 (1996); G. Hougham, G. Tesoro, and J. Shaw, *Polym. Mater. Sci. Eng.*, **61**, 369 (1989); V. Percec and B. C. Auman, *Makromol. Chem.*, **185**, 617 (1984); "Synthesis and characterization of New Fluorescent Poly(arylene ethers)," S. Matsuo, N. Yakoh, S. Chino, M. Mitani, and S. Tagami, *Journal of Polymer Science: Part A: Polymer Chemistry*, **32**, 1071 (1994); "Synthesis of a Novel Naphthalene-Based Poly(arylene ether ketone) with High Solubility and Thermal Stability," Mami Ohno, Toshikazu Takata, and Takeshi Endo, *Macromolecules*, **27**, 3447 (1994); "Synthesis and Characterization of New Aromatic Poly(ether ketones)," F. W. Mercer, M. T. McKenzie, G. Merlino, and M. M. Fone, J. *of Applied Polymer Science*, **56**, 1397 (1995); H. C. Zhang, T. L. Chen, Y. G. Yuan, Chinese Patent CN 85106751 (1991); "Static and laser light scattering study of novel thermoplastics. 1. Phenolphthalein poly(aryl ether ketone)," C. Wu, S. Bo, M. Siddiq, G. Yang and T. Chen, *Macromolecules*, **29**, 2989 (1996); "Synthesis of t-Butyl-Substituted Poly(ether ketone) by Nickel-Catalyzed Coupling Polymerization of Aromatic Dichloride", M. Ueda, Y. Seino, Y. Haneda, M. Yoneda, and J.-I. Sugiyama, *Journal of Polymer Science: Part A: Polymer Chemistry*, **32**, 675 (1994); "Reaction Mechanisms: Comb-Like Polymers and Graft Copolymers from Macromers 2. Synthesis, Characterization and Homopolymerization of a Styrene Macromer of Poly(2,6-dimethyl-1,4-phenylene Oxide)," V. Percec, P. L. Rinaldi, and B. C. Auman, *Polymer Bulletin*, **10**, 397 (1983); *Handbook of Polymer Synthesis Part A*, Hans R. Kricheldorf, ed., Marcel Dekker, Inc., New York-Basel-Hong Kong (1992); and "Introduction of Carboxyl Groups into Crosslinked Polystyrene," C. R. Harrison, P. Hodge, J. Kemp, and G. M. Perry, *Die Makromolekulare Chemie*, **176**, 267 (1975), the disclosures of each of which are totally incorporated herein by reference.

For applications wherein the photopatternable polymer is to be used as a layer in a thermal ink jet printhead, the polymer preferably has a number average molecular weight of from about 3,000 to about 20,000, more preferably from about 3,000 to about 10,000, and even more preferably from about 3,500 to about 6,500, although the molecular weight can be outside this range.

The polymer to be functionalized with epoxy or allyl ether groups can be functionalized by any desired or suitable process. One method entails preparation of a haloalkylated intermediate, followed by substitution with unsaturated ether or allyl ether groups and, if desired, subsequent epoxidation of the unsaturated ether or allyl ether groups. Haloalkylation of the polymer can be carried out by any suitable or desired process. For example, suitable haloalkylation processes include reaction of the polymers with formaldehyde and hydrohalic acid, bis(halomethyl) ether, halomethyl methyl ether, octylhalomethyl ether, or the like, generally in the presence of a Lewis acid catalyst. Bromination of a methyl group on the polymer can also be accomplished with elemental bromine via a free radical process initiated by, for example, a peroxide initiator or light. Halogen atoms can be substituted for other halogens already on a halomethyl group by, for example, reaction with the appropriate hydrohalic acid or halide salt. Methods for the haloalkylation of polymers are also disclosed in, for example, "Chloromethylation of Condensation Polymers Containing an oxy-1,4-phenylene Backbone," W. H. Daly et al., *Polymer Preprints*, Vol. 20, No. 1, 835 (1979), the disclosure of which is totally incorporated herein by reference.

Haloalkylation of the polymer can be accomplished by reacting the polymer with an acetyl halide and dimethoxymethane in the presence of a halogen-containing Lewis acid catalyst such as those of the general formula





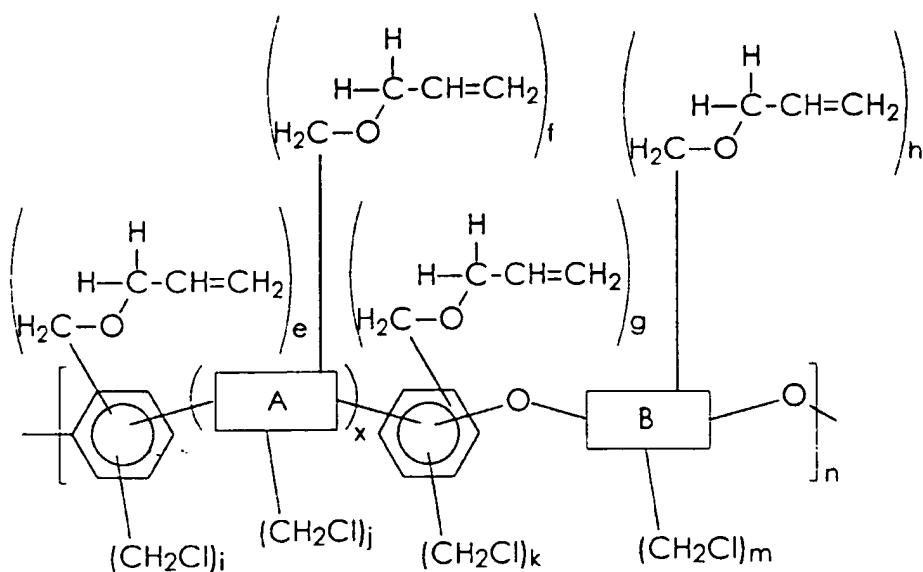
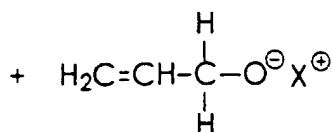
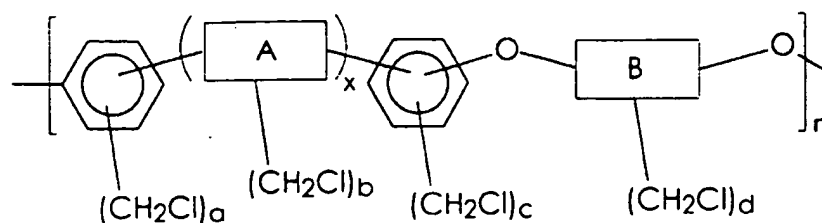
wherein n is an integer of 1, 2, 3, 4, or 5, M represents a boron atom or a metal atom, such as tin, aluminum, zinc, antimony, iron (III), gallium, indium, arsenic, mercury, copper, platinum, palladium, or the like, and X represents a halogen atom, such as fluorine, chlorine, bromine, or iodine, with specific examples including  $\text{SnCl}_4$ ,  $\text{AlCl}_3$ ,  $\text{ZnCl}_2$ ,  $\text{AlBr}_3$ ,  $\text{BF}_3$ ,  $\text{SbF}_5$ ,  $\text{FeI}_3$ ,  $\text{GaBr}_3$ ,  $\text{InCl}_3$ ,  $\text{AsI}_5$ ,  $\text{HgBr}_2$ ,  $\text{CuCl}$ ,  $\text{PdCl}_2$ , or  $\text{PtBr}_2$ . One suitable haloalkylation process is described in US Serial No. 08/705,463.

The haloalkylated polymer is allyl ether substituted or epoxidized by first reacting the haloalkylated polymer with an unsaturated alcohol salt, such as an allyl alcohol salt, in solution. Examples of suitable unsaturated alcohol salts and allyl alcohol salts include sodium 2-allylphenolate, sodium 4-allylphenolate, sodium allyl alcoholate, corresponding salts with lithium, potassium, cesium, rubidium, ammonium, quaternary alkyl ammonium compounds, and the like. Unsaturated alcohol salts can be generated by the reaction of the alcohol with a base, such as sodium hydride, sodium hydroxide, or the like. The salt displaces the halide of the haloalkyl groups at between about 25 and about 100°C. Examples of solvents suitable for the reaction include polar aprotic solvents such as N,N-dimethylacetamide, dimethylsulfoxide, N-methylpyrrolidinone, dimethylformamide, tetrahydrofuran, and the like. Typically, the reactants are present in relative amounts with respect to each other of from about 1 to about 50 molar equivalents of unsaturated alcohol salt per haloalkyl group to be substituted, although the relative amounts can be outside this range. Typically, the reactants are present in solution in amounts of from about 5 to about 50 percent by weight solids, and preferably about 10 percent by weight solids, although the relative amounts can be outside this range.

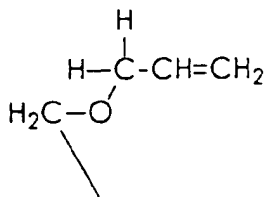
Typical reaction temperatures are from about 25 to about 100°C, and preferably from about 25 to about 50°C, although the temperature can be outside these ranges. Typical reaction times are from about 4 to about 24 hours, and preferably about 16 hours, although the time can be outside this range.

The general reaction scheme, illustrated below with a chloromethylated polymer and an allyl alcoholate salt, is as follows:



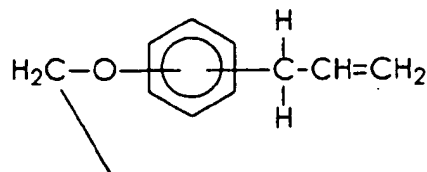


wherein X is any suitable cation, such as sodium, potassium, or the like, a, b, c, d, e, f, g, h, i, j, k, and m are each integers of 0, 1, 2, 3, or 4, provided that the sum of i+e is no greater than 4, the sum of j+f is no greater than 4, the sum of k+g is no greater than 4, and the sum of m+h is no greater than 4, provided that at least one of a, b, c, and d is equal to or greater than 1 in at least some of the monomer repeat units of the polymer, and provided that at least one of e, f, g, and h is equal to at least 1 in at least some of the monomer repeat units of the polymer, and n is an integer representing the number of repeating monomer units, and n is an integer representing the number of repeating monomer units. In the corresponding reaction with the 2-allylphenolate salt, the reaction proceeds as shown above except that the



groups shown above are replaced with

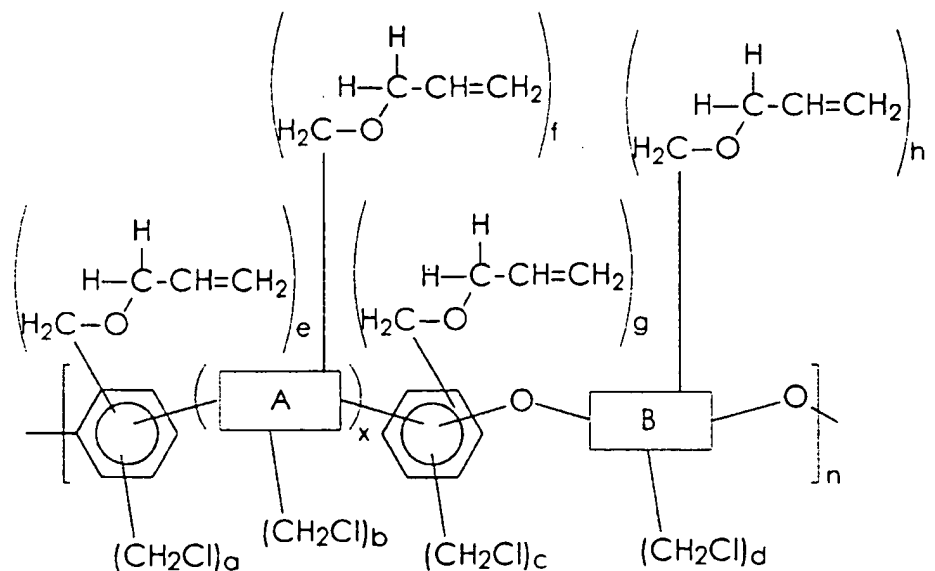




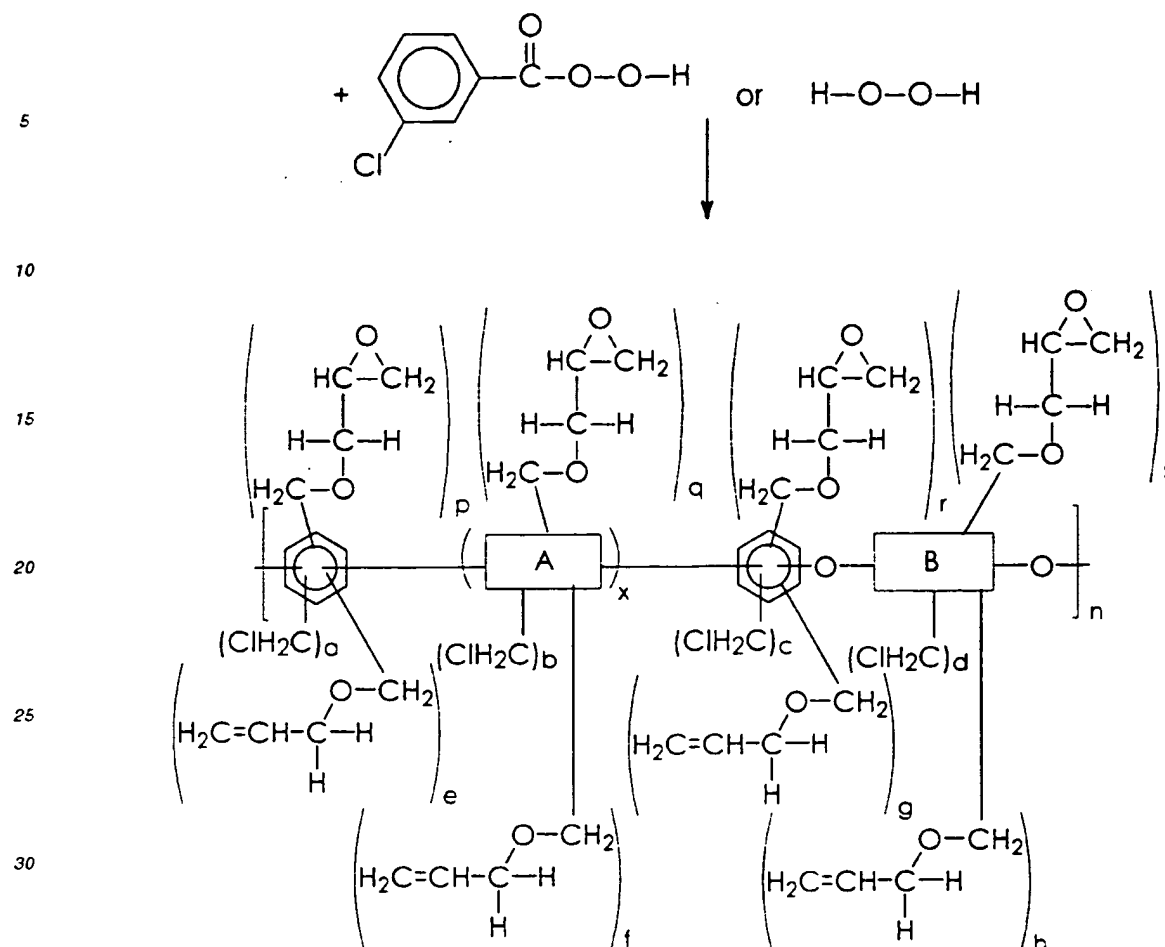
groups.

The allyl ether substituted polymer is suitable for photoinduced curing reactions. Alternatively, the allyl ether substituted polymer (or the unsaturated ether substituted polymer) can be used as an intermediate in the synthesis of the epoxidized polymer. This allyl ether or unsaturated ether substituted intermediate product is thereafter reacted with a peroxide, such as hydrogen peroxide, m-chloroperoxybenzoic acid, acetyl peroxide, and the like, as well as mixtures thereof, to yield the epoxidized polymer. Typically, the reactants are present in relative amounts with respect to each other of from approximately equivalent molar amounts of peroxide and the number of unsaturated groups desired to be converted to epoxide groups to an excess of between 10 and 100 mole percent of peroxide. The reaction preferably takes place in a dilute solution of about 1 percent by weight solids or less to prevent crosslinking.

The general reaction scheme, illustrated below with the allyl alcoholate substituents, is as follows:







35 wherein a, b, c, d, e, f, g, h, p, q, r, and s are each integers of 0, 1, 2, 3, or 4, provided that the sum of a+e+p is no greater than 4, the sum of b+f+q is no greater than 4, the sum of c+g+r is no greater than 4, and the sum of d+h+s is no greater than 4, provided that at least one of p, q, r, and s is equal to or greater than 1 in at least some of the monomer repeat units of the polymer, and n is an integer representing the number of repeating monomer units.

40 Some or all of the haloalkyl groups can be replaced with allyl ether or epoxy substituents. Longer reaction times generally lead to greater degrees of substitution of haloalkyl groups with allyl ether or epoxy substituents. In one preferred embodiment, some of the haloalkyl groups remain on the polymer (i.e., at least one of a, b, c, or d is equal to at least 1 in at least some of the monomer repeat units of the polymer). In this embodiment, the polymer can, if desired, be further reacted to convert the haloalkyl groups to, for example, unsaturated ester groups.

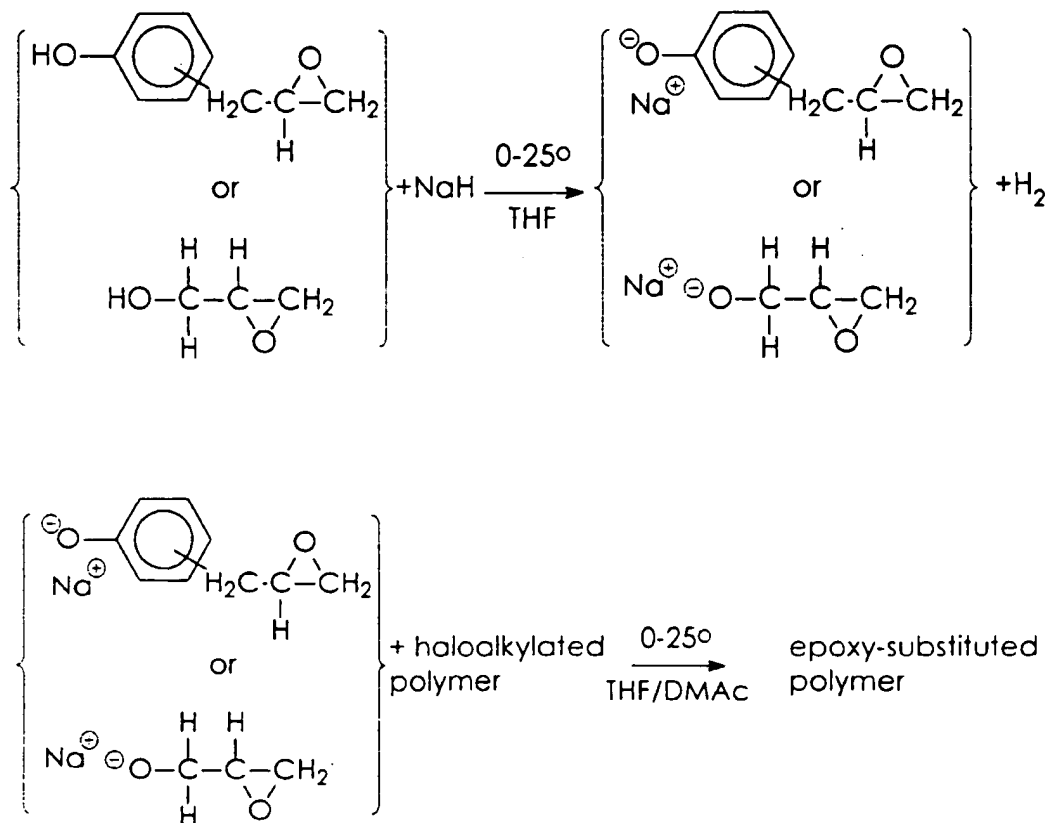
45 Typical reaction temperatures for the conversion of the unsaturated ether groups to the epoxy groups are from about 0 to about 50°C, and preferably from about 0 to about 25°C, although the temperature can be outside these ranges. Typical reaction times are from about 1 to about 24 hours, and preferably from about 4 to about 16 hours, although the time can be outside these ranges. Typical solvents for this reaction include methylene chloride, chloroform, and carbon tetrachloride.

50 The epoxidized polymer can also be prepared by reaction of the haloalkylated polymer with an epoxy-group-containing alcohol salt, such as a glycidolate salt, or an unsaturated alcohol salt, such as those set forth hereinabove, in the presence of a molar excess of base (with respect to the unsaturated alcohol salt or epoxy-group-containing alcohol salt), such as sodium hydride, sodium hydroxide, potassium carbonate, quaternary alkyl ammonium salts, or the like, under phase transfer conditions. Examples of suitable glycidolate salts include sodium glycidolate and the like. Typically, the reactants are present in relative amounts with respect to each other of from approximately equivalent molar amounts of alcohol and the number of unsaturated groups desired to be converted to epoxide groups. Typically, the reactants are present in solution in amounts of from about 1 to about 10 percent by weight solids, although other concentrations can be employed. The reaction with bases such as sodium hydroxide and potassium carbonate typically takes place at from about 25 to about 100°C. The reaction with sodium hydride with glycidol or the unsaturated alcohol



generally occurs at ice bath temperatures. Typical reaction times are about 16 hours, although other times may be employed. Examples of suitable solvents include dimethyl acetamide, tetrahydrofuran, and mixtures thereof.

The general reaction scheme is as follows:

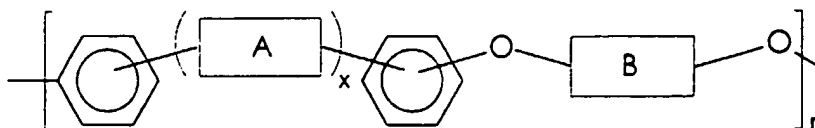


Unsaturated ether or allyl ether groups can also be placed on the haloalkylated polymer by other methods, such as by a Grignard reaction, a Wittig reaction, or the like.

In some instances, the terminal groups on the polymer can be selected by the stoichiometry of the polymer synthesis. For example, when a polymer is prepared by the reaction of 4,4'-dichlorobenzophenone and bis-phenol A in the presence of potassium carbonate in N,N-dimethylacetamide, if the bis-phenol A is present in about 7.5 to 8 mole percent excess, the resulting polymer generally is bis-phenol A-terminated (wherein the bis-phenol A moiety may or may not have one or more hydroxy groups thereon), and the resulting polymer typically has a polydispersity ( $M_w/M_n$ ) of from about 2 to about 3.5. When the bis-phenol A-terminated polymer is subjected to further reactions to place functional groups thereon, such as haloalkyl groups, and/or to convert one kind of functional group, such as a haloalkyl group, to another kind of functional group, such as an unsaturated ester group, the polydispersity of the polymer can rise to the range of from about 4 to about 6. In contrast, if the 4,4'-dichlorobenzophenone is present in about 7.5 to 8 mole percent excess, the reaction time is approximately half that required for the bis-phenol A excess reaction, the resulting polymer generally is benzophenone-terminated (wherein the benzophenone moiety may or may not have one or more chlorine atoms thereon), and the resulting polymer typically has a polydispersity of from about 2 to about 3.5. When the benzophenone-terminated polymer is subjected to further reactions to place functional groups thereon, such as haloalkyl groups, and/or to convert one kind of functional group, such as a haloalkyl group, to another kind of functional group, such as an unsaturated ester group, the polydispersity of the polymer typically remains in the range of from about 2 to about 3.5. Similarly, when a polymer is prepared by the reaction of 4,4'-difluorobenzophenone with either 9,9'-bis(4-hydroxyphenyl)fluorene or bis-phenol A in the presence of potassium carbonate in N,N-dimethylacetamide, if the 4,4'-difluorobenzophenone reactant is present in excess, the resulting polymer generally has benzophenone terminal groups (which may or may not have one or more fluorine atoms thereon). The well-known Carothers equation can be employed to calculate the stoichiometric offset required to obtain the desired molecular weight. (See, for example, William H. Carothers, "An Introduction to the General Theory of Condensation Polymers," *Chem. Rev.*, **8**, 353



(1931) and J. Amer. Chem. Soc., **51**, 2548 (1929); see also P. J. Flory, *Principles of Polymer Chemistry*, Cornell University Press, Ithaca, New York (1953); the disclosures of each of which are totally incorporated herein by reference.) More generally speaking, during the preparation of polymers of the formula



the stoichiometry of the polymer synthesis reaction can be adjusted so that the end groups of the polymer are derived from the "A" groups or derived from the "B" groups. Specific functional groups can also be present on these terminal "A" groups or "B" groups, such as ethynyl groups or other thermally sensitive groups, hydroxy groups which are attached to the aromatic ring on an "A" or "B" group to form a phenolic moiety, halogen atoms which are attached to the "A" or "B" group, or the like.

Polymers with end groups derived from the "A" group, such as benzophenone groups or halogenated benzophenone groups, may be preferred for some applications because both the syntheses and some of the reactions of these materials to place substituents thereon may be easier to control and may yield better results with respect to, for example, cost, molecular weight, molecular weight range, and polydispersity ( $M_w/M_n$ ) compared to polymers with end groups derived from the "B" group, such as bis-phenol A groups (having one or more hydroxy groups on the aromatic rings thereof) or other phenolic groups. While not being limited to any particular theory, it is believed that the haloalkylation reaction in particular proceeds most rapidly on the phenolic tails when the polymer is bis-phenol A terminated. Moreover, it is believed that halomethylated groups on phenolic-terminated polymers may be particularly reactive to subsequent crosslinking or chain extension. In contrast, it is generally believed that halomethylation does not take place on the terminal aromatic groups with electron withdrawing substituents, such as benzophenone, halogenated benzophenone, or the like. The "A" group terminated materials may also function as an adhesive, and in applications such as thermal ink jet printheads, the use of the crosslinked "A" group terminated polymer may reduce or eliminate the need for an epoxy adhesive to bond the heater plate to the channel plate.

If desired, to reduce the amount of residual halogen in a photoresist or other composition containing the polymers of the present invention, thereby also reducing or eliminating the generation of hydrohalic acid during a subsequent thermal curing step, any residual halogen atoms or haloalkyl groups on the photopatternable polymer can be converted to methoxy groups, hydroxide groups, acetoxy groups, amine groups, or the like by any desired process, including those processes disclosed hereinabove, those disclosed in, for example, British Patent 863,702, *Chem Abstr.* **55**, 18667b (1961), and other publications previously incorporated herein by reference, and the like.

The photopatternable polymer can be cured by uniform exposure to actinic radiation at wavelengths and/or energy levels capable of causing crosslinking or chain extension of the polymer through the photosensitivity-imparting groups. Alternatively, the photopatternable polymer is developed by imagewise exposure of the material to radiation at a wavelength and/or at an energy level to which the photosensitivity-imparting groups are sensitive. Typically, a photoresist composition will contain the photopatternable polymer, an optional solvent for the photopatternable polymer, an optional sensitizer, and an optional photoinitiator. Solvents may be particularly desirable when the uncrosslinked photopatternable polymer has a high  $T_g$ . The solvent and photopatternable polymer typically are present in relative amounts of from 0 to about 99 percent by weight solvent and from about 1 to 100 percent polymer, preferably are present in relative amounts of from about 20 to about 60 percent by weight solvent and from about 40 to about 80 percent by weight polymer, and more preferably are present in relative amounts of from about 30 to about 60 percent by weight solvent and from about 40 to about 70 percent by weight polymer, although the relative amounts can be outside these ranges.

Sensitizers absorb light energy and facilitate the transfer of energy to unsaturated bonds which can then react to crosslink or chain extend the resin. Sensitizers frequently expand the useful energy wavelength range for photoexposure, and typically are aromatic light absorbing chromophores. Sensitizers can also lead to the formation of photoinitiators, which can be free radical or ionic. When present, the optional sensitizer and the photopatternable polymer typically are present in relative amounts of from about 0.1 to about 20 percent by weight sensitizer and from about 80 to about 99.9 percent by weight photopatternable polymer, and preferably are present in relative amounts of from about 1 to about 10 percent by weight sensitizer and from about 90 to about 99 percent by weight photopatternable polymer, although the relative amounts can be outside these ranges.

Photoinitiators generally generate ions or free radicals which initiate polymerization upon exposure to actinic radiation. When present, the optional photoinitiator and the photopatternable polymer typically are present in relative amounts of from about 0.1 to about 20 percent by weight photoinitiator and from about 80 to about 99.9 percent by weight photopatternable polymer, and preferably are present in relative amounts of from about 1 to about 10 percent

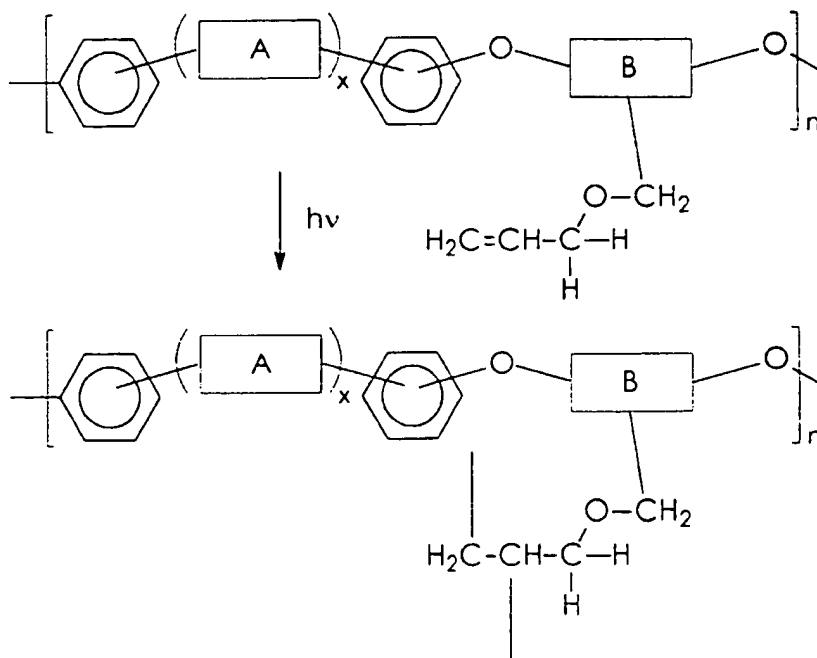


by weight photoinitiator and from about 90 to about 99 percent by weight photopatternable polymer, although the relative amounts can be outside these ranges.

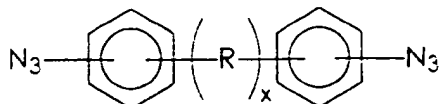
A single material can also function as both a sensitizer and a photoinitiator.

Examples of specific sensitizers and photoinitiators include Michler's ketone (Aldrich Chemical Co.), Darocure 1173, Darocure 4265, Irgacure 184, Irgacure 261, and Irgacure 907 (available from Ciba-Geigy, Ardsley, New York), and mixtures thereof. Further background material on initiators is disclosed in, for example, Ober et al., *J.M.S. - Pure Appl. Chem.*, **A30** (12), 877-897 (1993); G. E. Green, B. P. Stark, and S. A. Zahir, "Photocrosslinkable Resin Systems," *J. Macro. Sci. -- Revs. Macro. Chem.*, **C21**(2), 187 (1981); H. F. Gruber, "Photoinitiators for Free Radical Polymerization," *Prog. Polym. Sci.*, Vol. 17, 953 (1992); Johann G. Kloosterboer, "Network Formation by Chain Crosslinking Photopolymerization and Its Applications in Electronics," *Advances in Polymer Science*, **89**, Springer-Verlag Berlin Heidelberg (1988); and "Diaryliodonium Salts as Thermal Initiators of Cationic Polymerization," J. V. Crivello, T.P. Lockhart, and J. L. Lee, *J. of Polymer Science: Polymer Chemistry Edition*, **21**, 97 (1983), the disclosures of each of which are totally incorporated herein by reference. Sensitizers are available from, for example, Aldrich Chemical Co., Milwaukee, WI, and Pfaltz and Bauer, Waterbury, CT. Benzophenone and its derivatives can function as photosensitizers. Triphenylsulfonium and diphenyl iodonium salts are examples of typical cationic photoinitiators.

A photoresist containing the allyl ether substituted polymer is developed by imagewise exposure of the material to radiation at a wavelength to which it is sensitive. While not being limited to any particular theory, it is believed that exposure to, for example, ultraviolet radiation generally opens the ethylenic linkage in the allyl ether groups and leads to crosslinking or chain extension at the "long" bond sites as shown below:

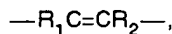


Alternatively, one specific example of a class of suitable sensitizers or initiators for the allyl-substituted polymers is that of bis(azides), of the general formula

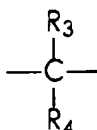


wherein R is

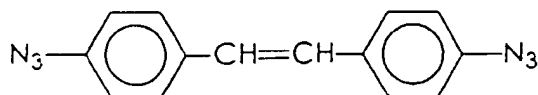




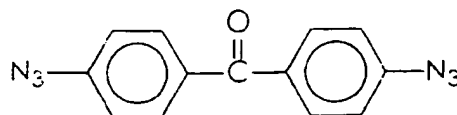
or



wherein  $\text{R}_1$ ,  $\text{R}_2$ ,  $\text{R}_3$ , and  $\text{R}_4$  each, independently of the others, is a hydrogen atom, an alkyl group, including saturated, unsaturated, and cyclic alkyl groups, preferably with from 1 to about 30 carbon atoms, and more preferably with from 1 to about 6 carbon atoms, a substituted alkyl group, an aryl group, preferably with from 6 to about 18 carbon atoms, and more preferably with about 6 carbon atoms, a substituted aryl group, an arylalkyl group, preferably with from 7 to about 48 carbon atoms, and more preferably with from about 7 to about 8 carbon atoms, or a substituted arylalkyl group, and  $x$  is 0 or 1, wherein the substituents on the substituted alkyl, aryl, and aryl groups can be (but are not limited to) alkyl groups, including saturated, unsaturated, linear, branched, and cyclic alkyl groups, preferably with from 1 to about 6 carbon atoms, substituted alkyl groups, preferably with from 1 to about 6 carbon atoms, aryl groups, preferably with from 6 to about 24 carbon atoms, substituted aryl groups, preferably with from 6 to about 24 carbon atoms, arylalkyl groups, preferably with from 7 to about 30 carbon atoms, substituted arylalkyl groups, preferably with from 7 to about 30 carbon atoms, alkoxy groups, preferably with from 1 to about 6 carbon atoms, substituted alkoxy groups, preferably with from 1 to about 6 carbon atoms, aryloxy groups, preferably with from 6 to about 24 carbon atoms, substituted aryloxy groups, preferably with from 6 to about 24 carbon atoms, arylalkyloxy groups, preferably with from 7 to about 30 carbon atoms, substituted arylalkyloxy groups, preferably with from 7 to about 30 carbon atoms, amine groups, imine groups, ammonium groups, pyridine groups, pyridinium groups, ether groups, ester groups, amide groups, carbonyl groups, thiocarbonyl groups, sulfate groups, sulfonate groups, sulfide groups, sulfoxide groups, phosphine groups, phosphonium groups, phosphate groups, mercapto groups, nitroso groups, sulfone groups, acyl groups, acid anhydride groups, azide groups, and the like, wherein the substituents on the substituted alkyl groups, substituted aryl groups, substituted arylalkyl groups, substituted alkoxy groups, substituted aryloxy groups, and substituted arylalkyloxy groups can be (but are not limited to) hydroxy groups, amine groups, imine groups, ammonium groups, pyridine groups, pyridinium groups, ether groups, aldehyde groups, ketone groups, ester groups, amide groups, carboxylic acid groups, carbonyl groups, thiocarbonyl groups, sulfate groups, sulfonate groups, sulfide groups, sulfoxide groups, phosphine groups, phosphonium groups, phosphate groups, cyano groups, nitrile groups, mercapto groups, nitroso groups, halogen atoms, nitro groups, sulfone groups, acyl groups, acid anhydride groups, azide groups, mixtures thereof, and the like, wherein any two or more substituents can be joined together to form a ring. Examples of suitable bis(azides) include 4,4'-diazidostilbene, of the formula

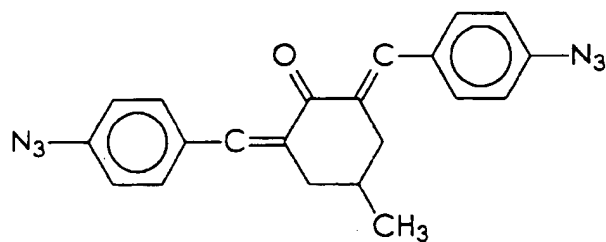


4,4'-diazidobenzophenone, of the formula

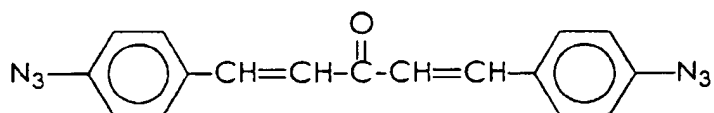




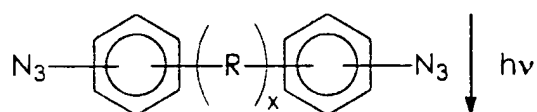
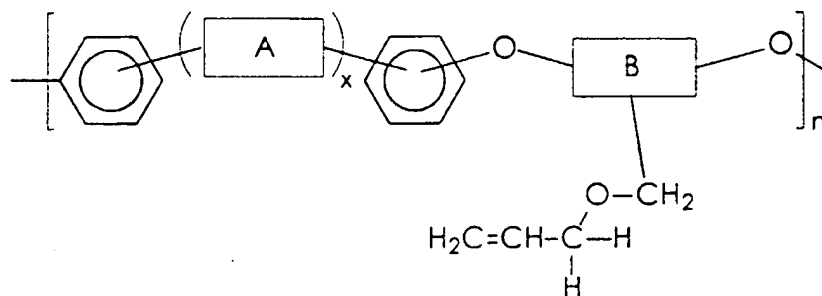
2,6-di-(4'-azidobenzal)-4-methylcyclohexanone, of the formula



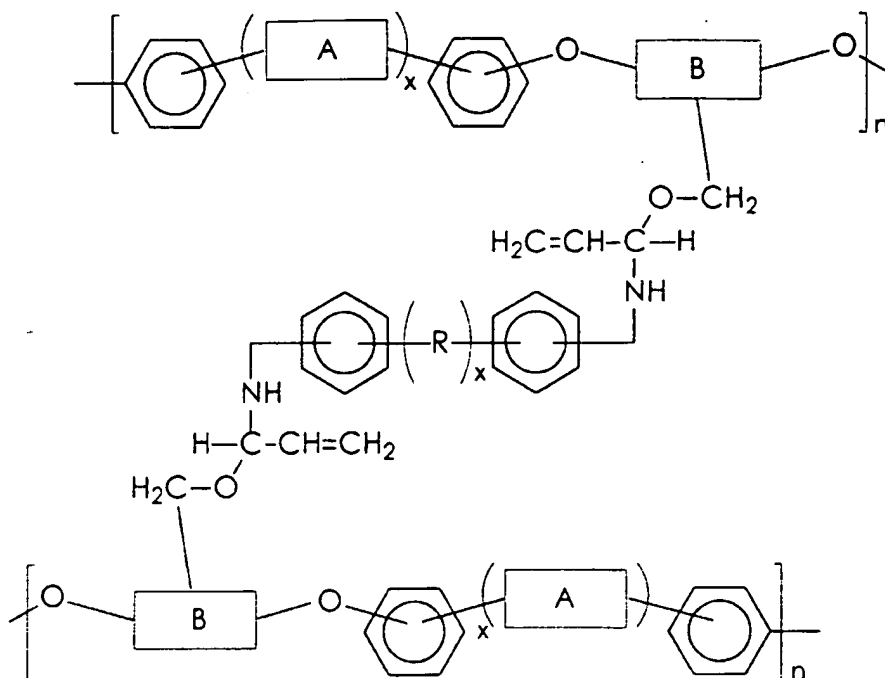
4,4'-diazidobenzalacetone, of the formula



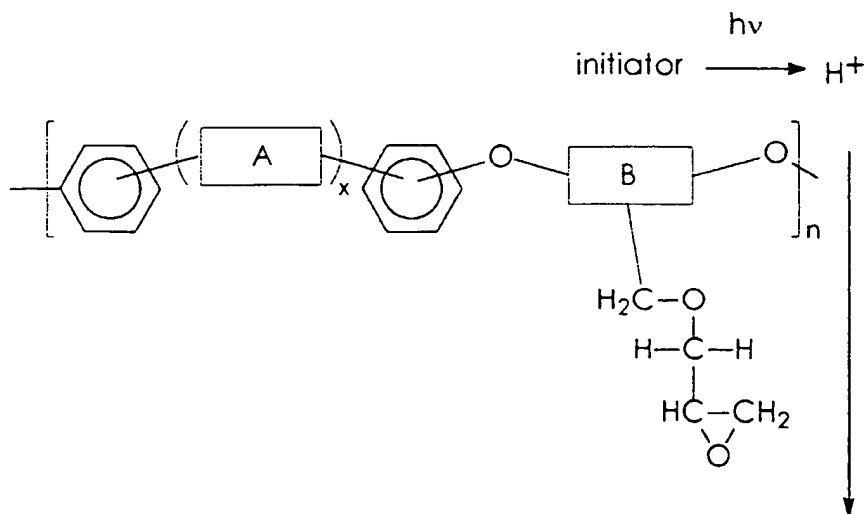
and the like. While not being limited to any particular theory, it is believed that exposure to, for example, ultraviolet radiation enables curing, as illustrated below



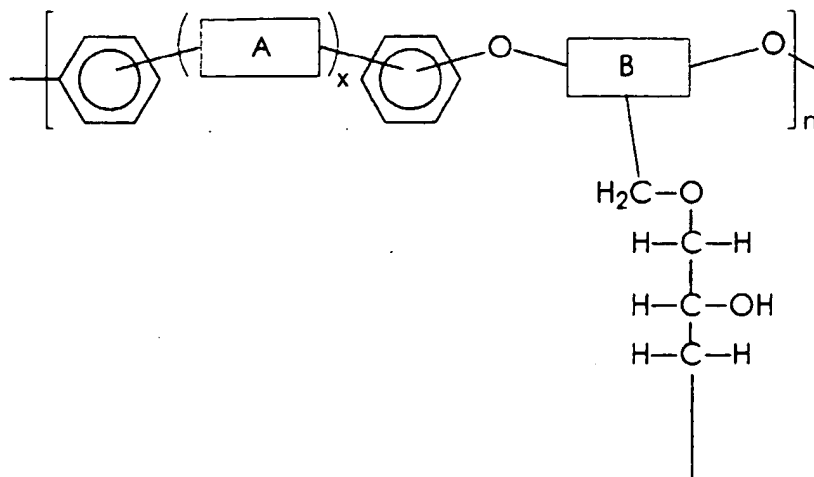




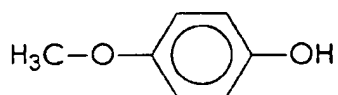
The photoresist containing the epoxidized polymer is developed by imagewise exposure of the material to radiation at a wavelength to which it is sensitive. While not being limited to any particular theory, it is believed that exposure to, for example, ultraviolet radiation generally causes generation of acidic species by the initiator, followed by reaction of the acidic species with the epoxy groups to cause ring opening and crosslinking or chain extension at the "long" bond sites as shown below:



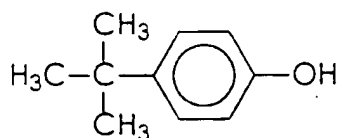




20 Inhibitors may also optionally be present in the photoresist containing the photopatternable polymer. Examples of suitable inhibitors include MEHQ, a methyl ether of hydroquinone, of the formula



30 t-butylcatechol, of the formula



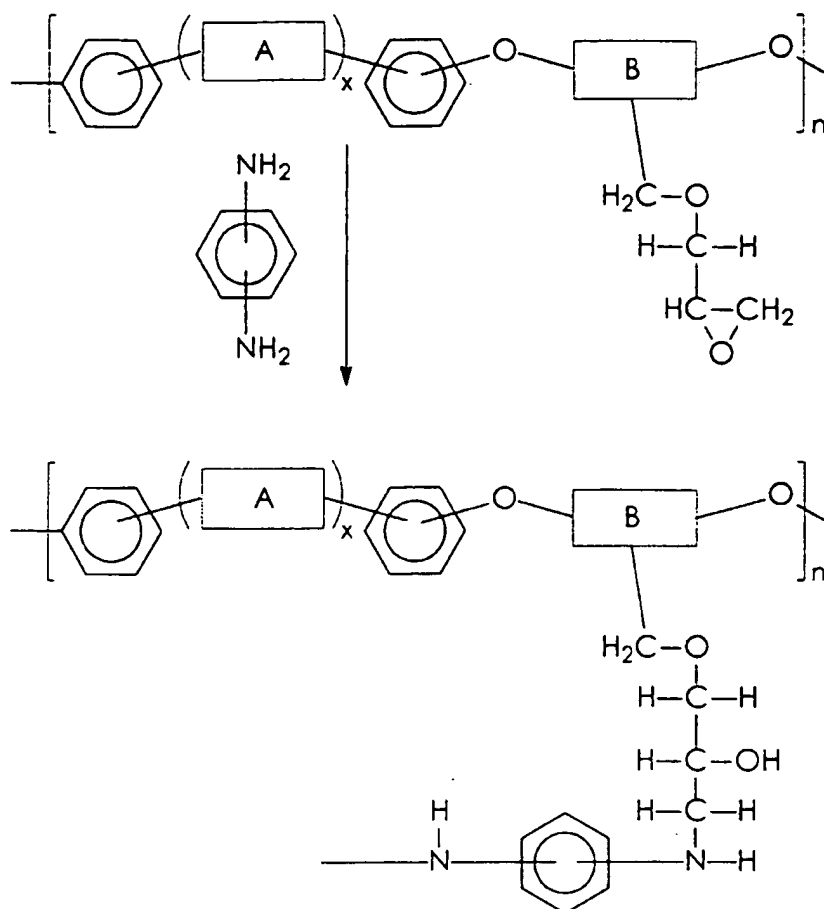
40 hydroquinone, of the formula



and the like, the inhibitor typically present in an amount of from about 500 to about 1,500 parts per million by weight of a photoresist solution containing about 40 percent by weight polymer solids, although the amount can be outside this range.

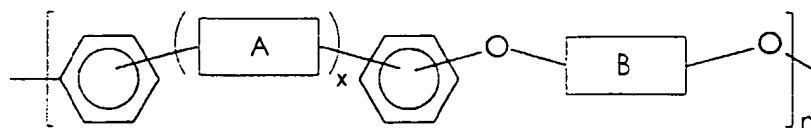
50 Amine curing of the epoxidized polymer is also possible, with curing occurring upon the application of heat. While not being limited to any particular theory, it is believed that the curing scheme in one example is as follows:





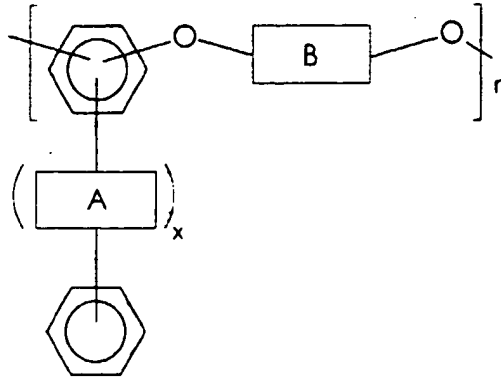
35 Many of the photosensitivity-imparting groups which are indicated above as being capable of enabling crosslinking or chain extension of the polymer upon exposure to actinic radiation can also enable crosslinking or chain extension of the polymer upon exposure to elevated temperatures; thus the polymers of the present invention can also, if desired, be used in applications wherein thermal curing is employed.

In all of the above reactions and substitutions illustrated above for the polymer of the formula



it is to be understood that analogous reactions and substitutions will occur for the polymer of the formula





Photopatternable epoxidized polymers prepared by the process of the present invention can be used as components in ink jet printheads. The printheads of the present invention can be of any suitable configuration. An example of a suitable configuration, suitable in this instance for thermal ink jet printing, is illustrated schematically in Figure 1, which depicts an enlarged, schematic isometric view of the front face 29 of a printhead 10 showing the array of droplet emitting nozzles 27. Referring also to Figure 2, discussed later, the lower electrically insulating substrate or heating element plate 28 has the heating elements 34 and addressing electrodes 33 patterned on surface 30 thereof, while the upper substrate or channel plate 31 has parallel grooves 20 which extend in one direction and penetrate through the upper substrate front face edge 29. The other end of grooves 20 terminate at slanted wall 21, the floor 41 of the internal recess 24 which is used as the ink supply manifold for the capillary filled ink channels 20, has an opening 25 therethrough for use as an ink fill hole. The surface of the channel plate with the grooves are aligned and bonded to the heater plate 28, so that a respective one of the plurality of heating elements 34 is positioned in each channel, formed by the grooves and the lower substrate or heater plate. Ink enters the manifold formed by the recess 24 and the lower substrate 28 through the fill hole 25 and by capillary action, fills the channels 20 by flowing through an elongated recess 38 formed in the thick film insulative layer 18. The ink at each nozzle forms a meniscus, the surface tension of which prevents the ink from weeping therefrom. The addressing electrodes 33 on the lower substrate or channel plate 28 terminate at terminals 32. The upper substrate or channel plate 31 is smaller than that of the lower substrate in order that the electrode terminals 32 are exposed and available for wire bonding to the electrodes on the daughter board 19, on which the printhead 10 is permanently mounted. Layer 18 is a thick film passivation layer, discussed later, sandwiched between the upper and lower substrates. This layer is etched to expose the heating elements, thus placing them in a pit, and is etched to form the elongated recess to enable ink flow between the manifold 24 and the ink channels 20. In addition, the thick film insulative layer is etched to expose the electrode terminals.

A cross sectional view of Figure 1 is taken along view line 2-2 through one channel and shown as Figure 2 to show how the ink flows from the manifold 24 and around the end 21 of the groove 20 as depicted by arrow 23. As is disclosed in U.S. Patent 4,638,337, U.S. Patent 4,601,777, and U.S. Patent Re. 32,572, a plurality of sets of bubble generating heating elements 34 and their addressing electrodes 33 can be patterned on the polished surface of a single side polished (100) silicon wafer. Prior to patterning, the multiple sets of printhead electrodes 33, the resistive material that serves as the heating elements 34, and the common return 35, the polished surface of the wafer is coated with an underglaze layer 39 such as silicon dioxide, having a typical thickness of from about 500nm (5,000 Angstroms) to about 2 micrometers (microns), although the thickness can be outside this range. The resistive material can be a doped polycrystalline silicon, which can be deposited by chemical vapor deposition (CVD) or any other well known resistive material such as zirconium boride ( $ZrB_2$ ). The common return and the addressing electrodes are typically aluminum leads deposited on the underglaze and over the edges of the heating elements. The common return ends or terminals 37 and addressing electrode terminals 32 are positioned at predetermined locations to allow clearance for wire bonding to the electrodes (not shown) of the daughter board 19, after the channel plate 31 is attached to make a printhead. The common return 35 and the addressing electrodes 33 are deposited to a thickness typically of from about 0.5 to about 3 micrometers (microns), although the thickness can be outside this range, with the preferred thickness being 1.5 micrometers (microns).

If polysilicon heating elements are used, they may be subsequently oxidized in steam or oxygen at a relatively high temperature, typically about 1,100°C although the temperature can be above or below this value, for a period of time typically of from about 50 to about 80 minutes, although the time period can be outside this range, prior to the deposition of the aluminum leads, in order to convert a small portion of the polysilicon to  $SiO_2$ . In such cases, the heating elements are thermally oxidized to achieve an overglaze (not shown) of  $SiO_2$  with a thickness typically of from about 50nm (500 Angstroms) to about 1 micrometer (micron), although the thickness can be outside this range, which



has good integrity with substantially no pinholes.

In one embodiment, polysilicon heating elements are used and an optional silicon dioxide thermal oxide layer 17 is grown from the polysilicon in high temperature steam. The thermal oxide layer is typically grown to a thickness of from about 0.5 to about 1 micron, although the thickness can be outside this range, to protect and insulate the heating elements from the conductive ink. The thermal oxide is removed at the edges of the polysilicon heating elements for attachment of the addressing electrodes and common return, which are then patterned and deposited. If a resistive material such as zirconium boride is used for the heating elements, then other suitable well known insulative materials can be used for the protective layer thereover. Before electrode passivation, a tantalum (Ta) layer (not shown) can be optionally deposited, typically to a thickness of about 1 micron, although the thickness can be above or below this value, on the heating element protective layer 17 for added protection thereof against the cavitation forces generated by the collapsing ink vapor bubbles during printhead operation. The tantalum layer is etched off all but the protective layer 17 directly over the heating elements using, for example,  $\text{CF}_4/\text{O}_2$  plasma etching. For polysilicon heating elements, the aluminum common return and addressing electrodes typically are deposited on the underglaze layer and over the opposing edges of the polysilicon heating elements which have been cleared of oxide for the attachment of the common return and electrodes.

For electrode passivation, a film 16 is deposited over the entire wafer surface, including the plurality of sets of heating elements and addressing electrodes. The passivation film 16 provides an ion barrier which will protect the exposed electrodes from the ink. Examples of suitable ion barrier materials for passivation film 16 include polyimide, plasma nitride, phosphorous doped silicon dioxide, materials disclosed herein as being suitable for insulative layer 18, and the like, as well as any combinations thereof. An effective ion barrier layer is generally achieved when its thickness is from about 100nm (1000 Angstroms) to about 10 micrometers (microns), although the thickness can be outside this range. In 300 dpi printheads, passivation layer 16 preferably has a thickness of about 3 micrometers (microns), although the thickness can be above or below this value. In 600 dpi printheads, the thickness of passivation layer 16 preferably is such that the combined thickness of layer 16 and layer 18 is about 25 micrometers (microns), although the thickness can be above or below this value. The passivation film or layer 16 is etched off of the terminal ends of the common return and addressing electrodes for wire bonding later with the daughter board electrodes. This etching of the silicon dioxide film can be by either the wet or dry etching method. Alternatively, the electrode passivation can be by plasma deposited silicon nitride ( $\text{Si}_3\text{N}_4$ ).

Next, a thick film type insulative layer 18, of a polymeric material discussed in further detail herein, is formed on the passivation layer 16, typically having a thickness of from about 10 to about 100 micrometers (microns) and preferably in the range of from about 25 to about 50 micrometers (microns), although the thickness can be outside these ranges. Even more preferably, in 300 dpi printheads, layer 18 preferably has a thickness of about 30 micrometers (microns), and in 600 dpi printheads, layer 18 preferably has a thickness of from about 20 to about 22 micrometers (microns), although other thicknesses can be employed. The insulative layer 18 is photolithographically processed to enable etching and removal of those portions of the layer 18 over each heating element (forming recesses 26), the elongated recess 38 for providing ink passage from the manifold 24 to the ink channels 20, and over each electrode terminal 32, 37. The elongated recess 38 is formed by the removal of this portion of the thick film layer 18. Thus, the passivation layer 16 alone protects the electrodes 33 from exposure to the ink in this elongated recess 38. Optionally, if desired, insulative layer 18 can be applied as a series of thin layers of either similar or different composition. Typically, a thin layer is deposited, photoexposed, partially cured, followed by deposition of the next thin layer, photoexposure, partial curing, and the like. The thin layers constituting thick film insulative layer 18 contain a polymer of the formula indicated hereinabove. In one embodiment of the present invention, a first thin layer is applied to contact layer 16, said first thin layer containing a mixture of a polymer of the formula indicated hereinabove and an epoxy polymer, followed by photoexposure, partial curing, and subsequent application of one or more successive thin layers containing a polymer of the formula indicated hereinabove.

Figure 3 is a similar view to that of Figure 2 with a shallow anisotropically etched groove 40 in the heater plate, which is silicon, prior to formation of the underglaze 39 and patterning of the heating elements 34, electrodes 33 and common return 35. This recess 40 permits the use of only the thick film insulative layer 18 and eliminates the need for the usual electrode passivating layer 16. Since the thick film layer 18 is impervious to water and relatively thick (typically from about 20 to about 40 microns, although the thickness can be outside this range), contamination introduced into the circuitry will be much less than with only the relatively thin passivation layer 16 well known in the art. The heater plate is a fairly hostile environment for integrated circuits. Commercial ink generally entails a low attention to purity. As a result, the active part of the heater plate will be at elevated temperature adjacent to a contaminated aqueous ink solution which undoubtedly abounds with mobile ions. In addition, it is generally desirable to run the heater plate at a voltage of from about 30 to about 50 volts, so that there will be a substantial field present. Thus, the thick film insulative layer 18 provides improved protection for the active devices and provides improved protection, resulting in longer operating lifetime for the heater plate.

When a plurality of lower substrates 28 are produced from a single silicon wafer, at a convenient point after the



underglaze is deposited, at least two alignment markings (not shown) preferably are photolithographically produced at predetermined locations on the lower substrates 28 which make up the silicon wafer. These alignment markings are used for alignment of the plurality of upper substrates 31 containing the ink channels. The surface of the single sided wafer containing the plurality of sets of heating elements is bonded to the surface of the wafer containing the plurality of ink channel containing upper substrates subsequent to alignment.

As disclosed in U.S. Patent 4,601,777 and U.S. Patent 4,638,337, the channel plate is formed from a two side polished, (100) silicon wafer to produce a plurality of upper substrates 31 for the printhead. After the wafer is chemically cleaned, a pyrolytic CVD silicon nitride layer (not shown) is deposited on both sides. Using conventional photolithography, a via for fill hole 25 for each of the plurality of channel plates 31 and at least two vias for alignment openings (not shown) at predetermined locations are printed on one wafer side. The silicon nitride is plasma etched off of the patterned vias representing the fill holes and alignment openings. A potassium hydroxide (KOH) anisotropic etch can be used to etch the fill holes and alignment openings. In this case, the [111] planes of the (100) wafer typically make an angle of about 54.7 degrees with the surface of the wafer. The fill holes are small square surface patterns, generally of about 20 mils (500 microns) per side, although the dimensions can be above or below this value, and the alignment openings are from about 60 to about 80 mils (1.5 to 3 millimeters) square, although the dimensions can be outside this range. Thus, the alignment openings are etched entirely through the 20 mil (0.5 millimeter) thick wafer, while the fill holes are etched to a terminating apex at about halfway through to three-quarters through the wafer. The relatively small square fill hole is invariant to further size increase with continued etching so that the etching of the alignment openings and fill holes are not significantly time constrained.

Next, the opposite side of the wafer is photolithographically patterned, using the previously etched alignment holes as a reference to form the relatively large rectangular recesses 24 and sets of elongated, parallel channel recesses that will eventually become the ink manifolds and channels of the printheads. The surface 22 of the wafer containing the manifold and channel recesses are portions of the original wafer surface (covered by a silicon nitride layer) on which an adhesive, such as a thermosetting epoxy, will optionally be applied later for bonding it to the substrate containing the plurality of sets of heating elements. The adhesive is applied in a manner such that it does not run or spread into the grooves or other recesses. The alignment markings can be used with, for example, a vacuum chuck mask aligner to align the channel wafer on the heating element and addressing electrode wafer. The two wafers are accurately mated and can be tacked together by partial curing of the adhesive.

Incorporation of the epoxy groups into the photopatternable polyarylene ether enables or improves adhesion of the polyarylene ether layer to the heater plate, and possibly also to the channel plate. Subsequent to imaging and during cure of the polyarylene ether, the epoxy groups react with the heater layer to form strong chemical bonds with that layer, improving adhesive strength and solvent resistance of the interface. The presence of the epoxy groups may also improve the hydrophilicity of the polyarylene ether and thus may improve the wetting properties of the layer, thereby improving the refill characteristics of the printhead.

Alternatively, the heating element and channel wafers can be given precisely diced edges and then manually or automatically aligned in a precision jig. Alignment can also be performed with an infrared aligner-bonder, with an infrared microscope using infrared opaque markings on each wafer to be aligned, or the like. The two wafers can then be cured in an oven or laminator to bond them together permanently. The channel wafer can then be milled to produce individual upper substrates. A final dicing cut, which produces end face 29, opens one end of the elongated groove 20 producing nozzles 27. The other ends of the channel groove 20 remain closed by end 21. However, the alignment and bonding of the channel plate to the heater plate places the ends 21 of channels 20 directly over elongated recess 38 in the thick film insulative layer 18 as shown in Figure 2 or directly above the recess 40 as shown in Figure 3 enabling the flow of ink into the channels from the manifold as depicted by arrows 23. The plurality of individual printheads produced by the final dicing are bonded to the daughter board and the printhead electrode terminals are wire bonded to the daughter board electrodes.

In one embodiment, a heater wafer with a phosphosilicate glass layer is spin coated with a solution of Z6020 adhesion promoter (0.01 weight percent in 95 parts methanol and 5 parts water, Dow Corning) at 3000 revolutions per minute for 10 seconds and dried at 100°C for between 2 and 10 minutes. The wafer is then allowed to cool at 25°C for 5 minutes before spin coating the photoresist containing the photopatternable polymer onto the wafer at between 1,000 and 3,000 revolutions per minute for between 30 and 60 seconds. The photoresist solution is made by dissolving polyarylene ether ketone with from about 1 to about 1.5 epoxy groups and from about 0.1 to about 1.0 chloromethyl groups per repeat unit and a number average molecular weight of from about 5,000 to about 7,000 (polydispersity ( $M_w/M_n$ ) of from about 2 to about 5) in N-methylpyrrolidinone at 40 weight percent solids with Michler's ketone (1.2 parts ketone per every 10 parts of 40 weight percent solids polymer solution). If desired, a curing agent, such as the "Y" curative (meta-phenylenediamine) or the like, as well as mixtures thereof, can also be included in the photoresist solution. The film is heated (soft baked) in an oven for between 10 and 15 minutes at 70°C. After cooling to 25°C over 5 minutes, the film is covered with a mask and exposed to 365 nanometer ultraviolet light, amounting to between 150 and 1,500 millijoules per cm<sup>2</sup>. The exposed wafer is then heated at 70°C for 2 minutes post exposure bake, followed



by cooling to 25°C over 5 minutes. The film is developed with any suitable developer, such as 60:40 chloroform/cyclohexanone, mixtures of cyclohexanone and methyl ethyl ketone, or the like, washed with 90:10 hexanes/cyclohexanone, and then dried at 70°C for 2 minutes. A second developer/wash cycle is carried out if necessary to obtain a wafer with clean features. The processed wafer is transferred to an oven at 25°C, and the oven temperature is raised from 25 to 90°C at 2°C per minute. The temperature is maintained at 90°C for 2 hours, and then increased to 260°C at 2°C per minute. The oven temperature is maintained at 260°C for 2 hours and then the oven is turned off and the temperature is allowed to cool gradually to 25°C. When thermal cure of the photoresist films is carried out under inert atmosphere, such as nitrogen or one of the noble gases, such as argon, neon, krypton, xenon, or the like, there is markedly reduced oxidation of the developed film and improved thermal and hydrolytic stability of the resultant devices. Moreover, adhesion of developed photoresist film is improved to the underlying substrate. If a second layer is spin coated over the first layer, the heat cure of the first developed layer can be stopped between 80 and 260°C before the second layer is spin coated onto the first layer. A second thicker layer is deposited by repeating the above procedure a second time. This process is intended to be a guide in that procedures can be outside the specified conditions depending on film thickness and photoresist molecular weight. Films at 30 micrometers (microns) have been developed with clean features at 600 dots per inch.

In another embodiment, the photopatternable polymer is admixed with an epoxy resin in relative amounts of from about 75 parts by weight photopatternable polymer and about 25 parts by weight epoxy resin to about 90 parts by weight photopatternable polymer and about 10 parts by weight epoxy resin.

The present invention also encompasses printing processes with printheads according to the present invention. One embodiment of the present invention is directed to an ink jet printing process which comprises (1) preparing an ink jet printhead comprising a plurality of channels, wherein the channels are capable of being filled with ink from an ink supply and wherein the channels terminate in nozzles on one surface of the printhead, said preparation being according to the process of the present invention; (2) filling the channels with an ink; and (3) causing droplets of ink to be expelled from the nozzles onto a receiver sheet in an image pattern. A specific embodiment of this process is directed to a thermal ink jet printing process, wherein the droplets of ink are caused to be expelled from the nozzles by heating selected channels in an image pattern. The droplets can be expelled onto any suitable receiver sheet, such as fabric, plain paper such as Xerox® 4024 or 4010, coated papers, or transparency materials.

All parts and percentages in the Examples are by weight unless otherwise indicated.

#### EXAMPLE I

(a) A solution of chloromethyl ether in methyl acetate was made by adding 282.68 grams (256 milliliters) of acetyl chloride to a mixture of dimethoxy methane (313.6 grams, 366.8 milliliters) and methanol (10 milliliters) in a 5 liter 3-neck round-bottom flask equipped with a mechanical stirrer, argon inlet, reflux condenser, and addition funnel. The solution was diluted with 1,066.8 milliliters of 1,1,2,2-tetrachloroethane and then tin tetrachloride (2.4 milliliters) was added via a gas-tight syringe along with 1,1,2,2-tetrachloroethane (133.2 milliliters) using an addition funnel. The reaction solution was heated to 500°C. Thereafter, a solution of poly(4-CPK-BPA) prepared as described in Example I (160.6 grams) in 1,000 milliliters of tetrachloroethane was added rapidly. The reaction mixture was then heated to reflux with an oil bath set at 110°C. After two hours reflux with continuous stirring, heating was discontinued and the mixture was allowed to cool to 25°C. The reaction mixture was transferred in stages to a 2 liter round bottom flask and concentrated using a rotary evaporator with gentle heating up to 50°C while reduced pressure was maintained with a vacuum pump trapped with liquid nitrogen. The concentrate was added to methanol (4 gallons) to precipitate the polymer using a Waring blender. The polymer was isolated by filtration and vacuum dried to yield 200 grams of poly(4-CPK-BPA) with 1.0 chloromethyl groups per repeat unit as identified using <sup>1</sup>H NMR spectroscopy.

(b) A 1-liter, 3-neck flask equipped with a mechanical stirrer, argon inlet, and addition funnel was charged with 175 milliliters of freshly distilled tetrahydrofuran. Sodium hydride (6 grams), obtained from Aldrich Chemical Co., Milwaukee, WI, was added, followed by addition of 2-allyl phenol (5 grams) dropwise, resulting in vigorous hydrogen gas evolution. Thereafter, a solution containing 5 grams of a chloromethylated polyarylene ether ketone prepared as described in Example II in 50 milliliters of tetrahydrofuran was added. Stirring at 25°C was continued for 48 hours. The resulting polymer was filtered and the supernatant fluid was concentrated using a rotary evaporator. The concentrate was then added to methanol to precipitate the polymer, followed by *in vacuo* drying of the polymer.

The dried polymer (0.2 grams) in methylene chloride (100 milliliters) was then treated with 1 gram of *m*-chloroperoxybenzoic acid (obtained from Aldrich Chemical Co., Milwaukee, WI) and magnetically stirred for 2 hours in a 200 milliliter bottle. The polymer was then added to saturated aqueous sodium bicarbonate (200 milliliters) and the methylene chloride was removed using a rotary evaporator. The resulting epoxidized polymer was filtered, washed with methanol (3 cups), and vacuum dried.



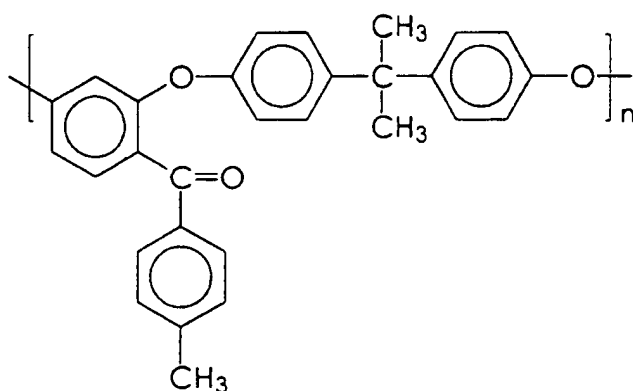
The epoxidized polymer in N-methyl pyrrolidinone (40 weight percent polymer solids) was rendered photochemically active by the addition of Irgacure 261 (obtained from Ciba-Geigy, Ardsley, NY) to the solution in an amount of 4 percent by weight of the polymer. Exposure to ultraviolet light, followed by heating to 70°C, and development with a cyclohexanone-methyl ethyl ketone mixture, yielded microlithographic patterns. Subsequent thermal curing to 260°C completely crosslinked the polymer, rendering it impervious to solvents such as N-methylpyrrolidinone, methylene chloride, acetone, and hexanes.

## EXAMPLE II

The process of Example I was repeated with the exception that 5 grams of allyl alcohol were used instead of the 2-allylphenol in part (b). Similar results were obtained.

## EXAMPLE III

(a) A polymer of the formula



wherein  $n$  represents the number of repeating monomer units was prepared as follows. A 250 milliliter, 3-neck round-bottom flask equipped with a Dean-Stark (Barrett) trap, condenser, mechanical stirrer, argon inlet, and stopper was situated in a silicone oil bath. 4'-Methylbenzoyl-2,4-dichlorobenzene (0.0325 mol, 8.6125 grams, prepared as described in Example XIV), bis-phenol A (Aldrich 23,965-8, 0.035 mol, 7.99 grams), potassium carbonate (10.7 grams), anhydrous *N,N*-dimethylacetamide (60 milliliters), and toluene (60 milliliters, 49.1 grams) were added to the flask and heated to 175°C (oil bath temperature) while the volatile toluene component was collected and removed. After 24 hours of heating at 175°C with continuous stirring, the reaction product was filtered and the filtrate was added to methanol to precipitate the polymer. The wet polymer cake was isolated by filtration, washed with water, then washed with methanol, and thereafter vacuum dried. The polymer (7.70 grams, 48% yield) was analyzed by gel permeation chromatography (gpc) (elution solvent was tetrahydrofuran) with the following results:  $M_n$  1,898;  $M_{peak}$  2,154;  $M_w$  2,470;  $M_z$  3,220, and  $M_{z+1}$  4,095.

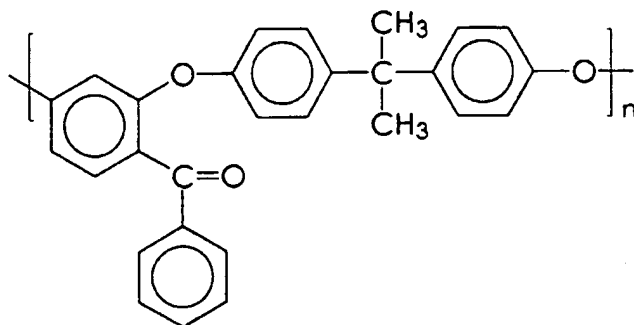
(b) The polymer obtained from (a) above is treated with 2-allyl phenol as described in Example I(b).

(c) The polymer obtained from (a) above is treated with allyl alcohol as described in Example II.

## EXAMPLE IV

(a) A polymer of the formula





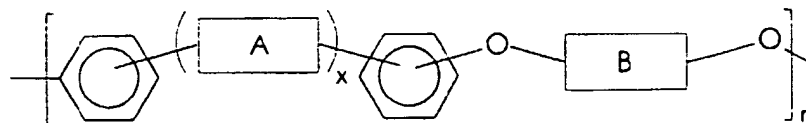
wherein  $n$  represents the number of repeating monomer units was prepared by repeating the process of Example XIX except that the 4'-methylbenzoyl-2,4-dichlorobenzene starting material was replaced with 8.16 grams (0.0325 mol) of benzoyl-2,4-dichlorobenzene, and the oil bath was heated to 170°C for 24 hours.

(b) The polymer obtained from (a) above is treated with 2-allyl phenol as described in Example I(b).

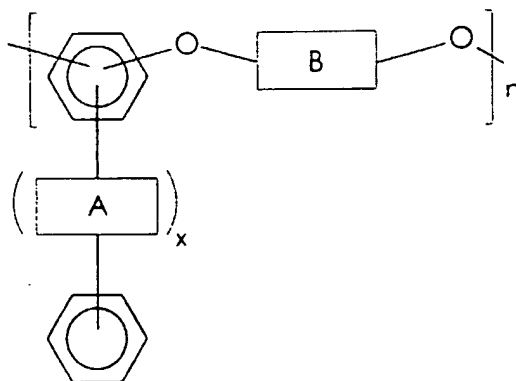
(c) The polymer obtained from (a) above is treated with allyl alcohol as described in Example II.

### Claims

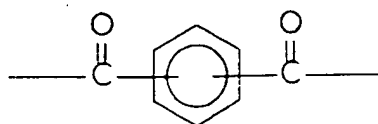
1. A composition which comprises a polymer containing at least some monomer repeat units with photosensitivity-imparting substituents which enable crosslinking or chain extension of the polymer upon exposure to actinic radiation, said polymer being of the formula



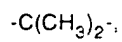
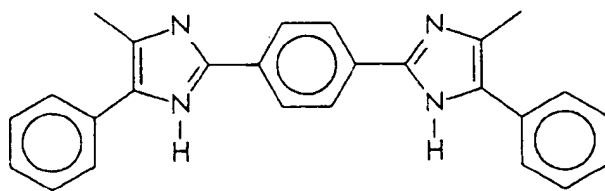
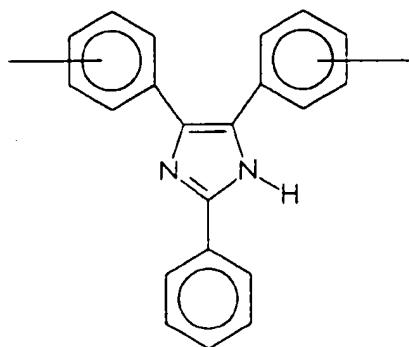
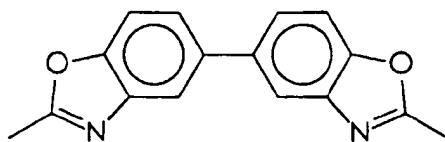
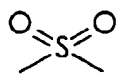
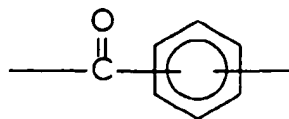
or



wherein  $x$  is an integer of 0 or 1,  $A$  is



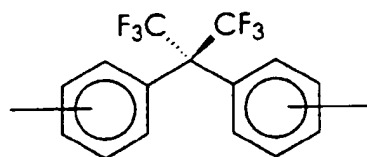




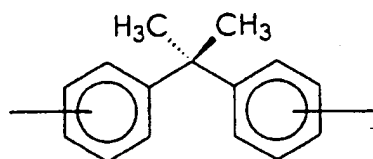
or mixtures thereof, B is



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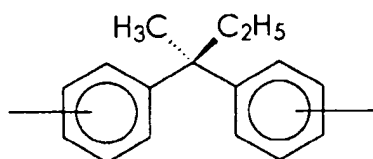


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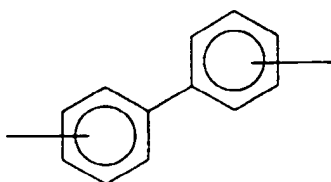
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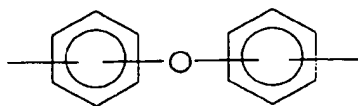
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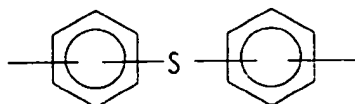


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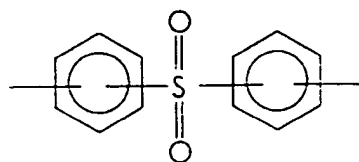


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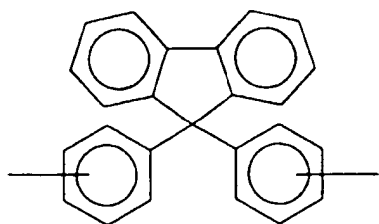
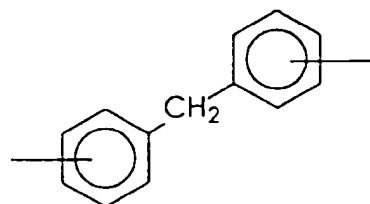
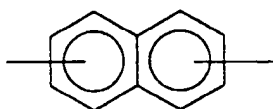
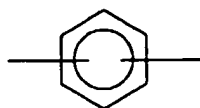
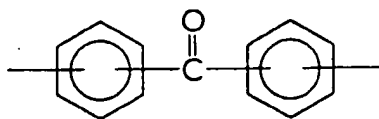


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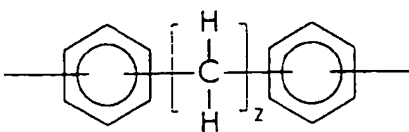
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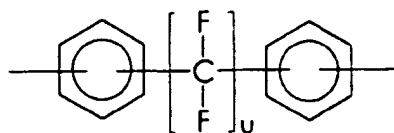


wherein v is an integer of from 1 to about 20,

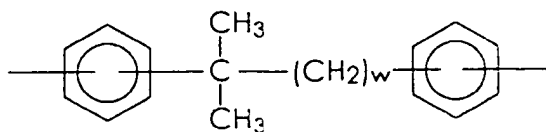
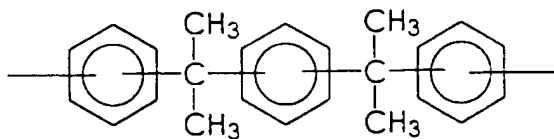
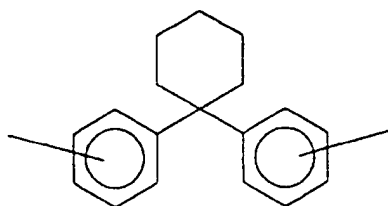
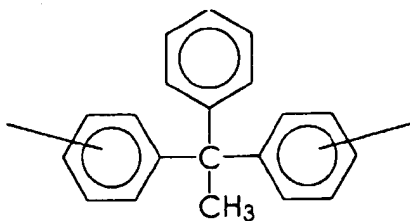


wherein z is an integer of from 2 to about 20,

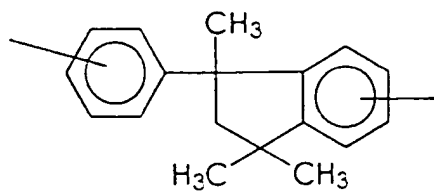




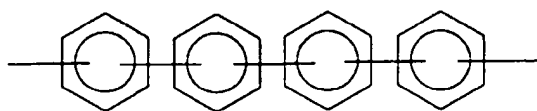
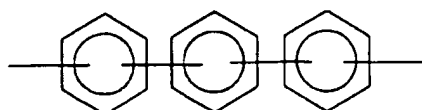
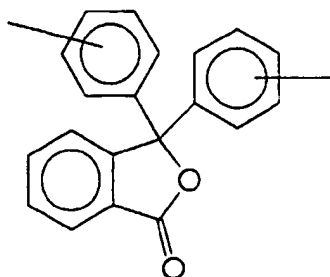
10 wherein u is an integer of from 1 to about 20,



50 wherein w is an integer of from 1 to about 20,

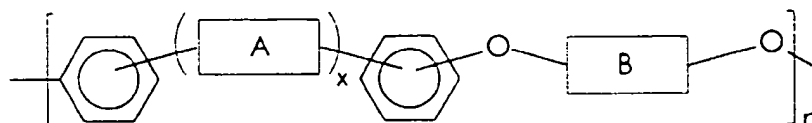






or mixtures thereof, and  $n$  is an integer representing the number of repeating monomer units, wherein said photosensitivity-imparting substituents are allyl ether groups, epoxy groups, or mixtures thereof.

2. A composition according to claim 1 further containing a second component selected from the group consisting of a sensitizer, a photoinitiator, a solvent, and any mixtures thereof.
3. A composition which comprises a crosslinked or chain extended polymer of the formula



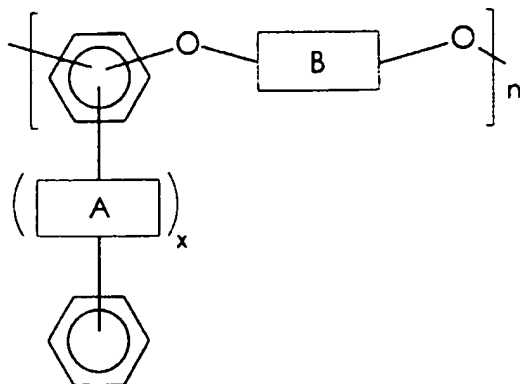
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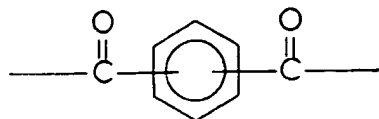
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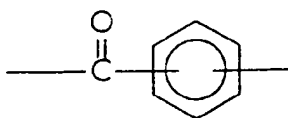


wherein x is an integer of 0 or 1, A is

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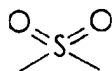


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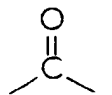


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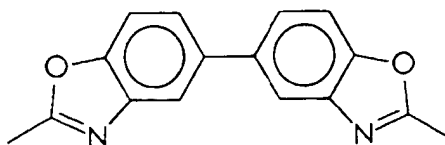


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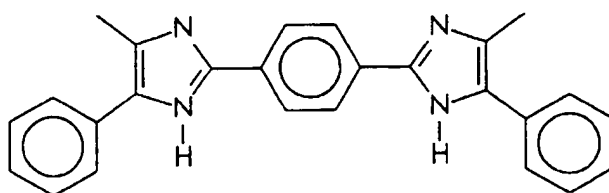
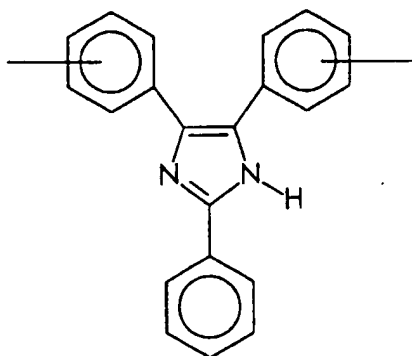
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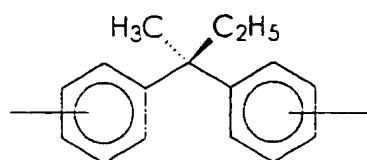
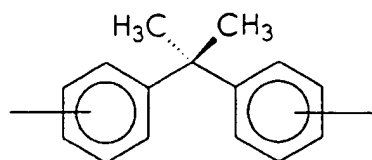
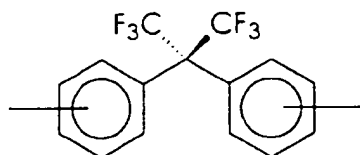




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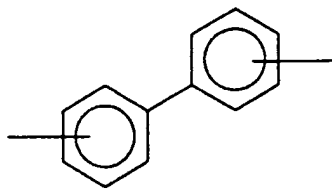
-C(CH<sub>3</sub>)<sub>2</sub>-

or mixtures thereof, B is

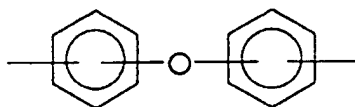




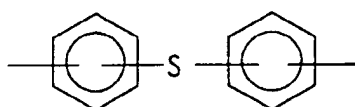
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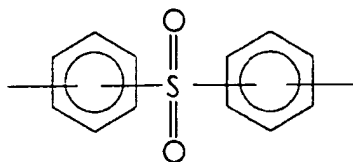


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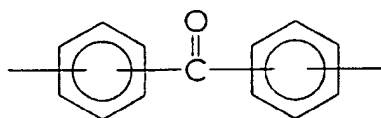
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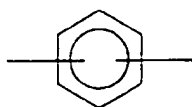
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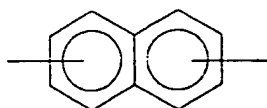


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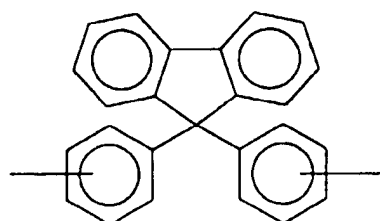
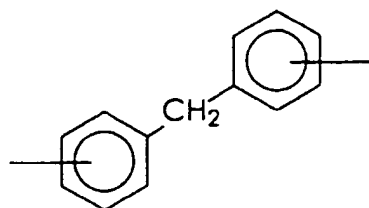


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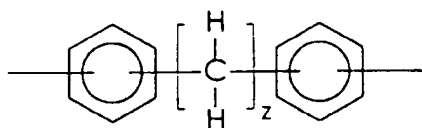


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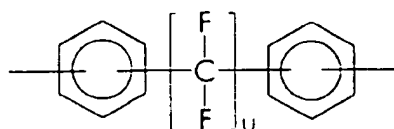




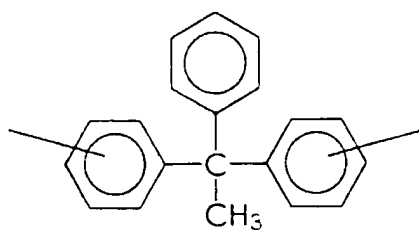
25 wherein v is an integer of from 1 to about 20,



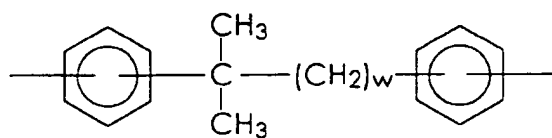
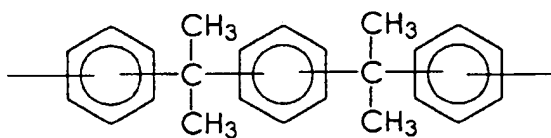
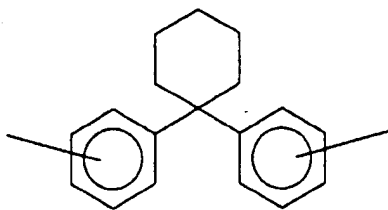
35 wherein z is an integer of from 2 to about 20,



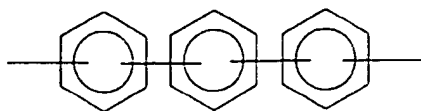
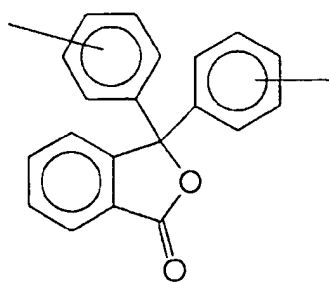
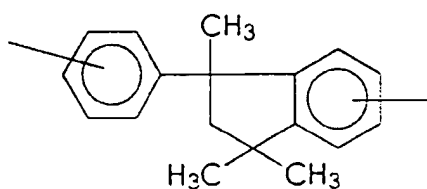
45 wherein u is an integer of from 1 to about 20,



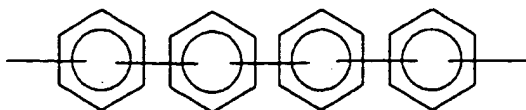




wherein w is an integer of from 1 to about 20,

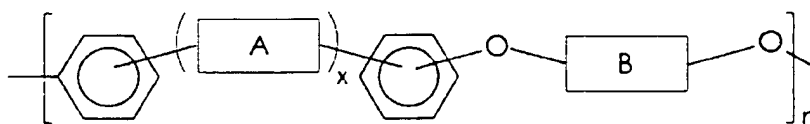




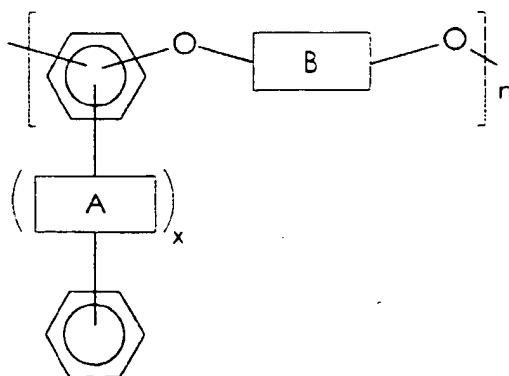


or mixtures thereof, and  $n$  is an integer representing the number of repeating monomer units, said crosslinking or chain extension occurring through linking groups selected from the group consisting of (a) those formed by a reaction between epoxy groups contained on at least some of the monomer repeat units of the polymer and an amine curing agent; and (b) those formed through photosensitivity-imparting allyl ether or epoxy group substituents contained on at least some of the monomer repeat units of the polymer upon exposure to actinic radiation.

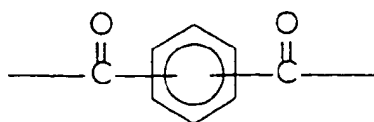
4. A composition according to any of claims 1 to 3 wherein the polymer has end groups derived from the "A" groups of the polymer.
5. A composition according to any of claims 1 to 3 wherein the polymer has end groups derived from the "B" groups of the polymer.
6. A process which comprises reacting a polymer containing at least some monomer repeat units with haloalkyl substituents thereon and of the formula



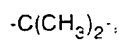
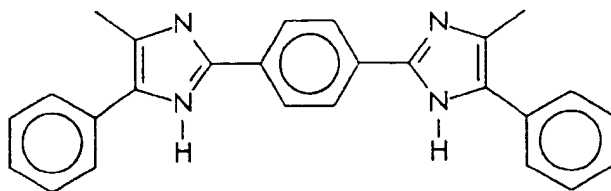
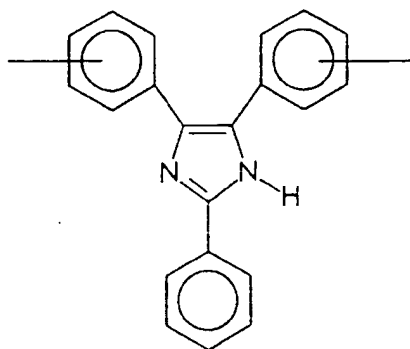
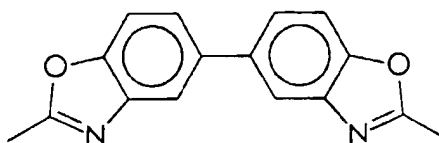
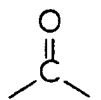
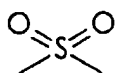
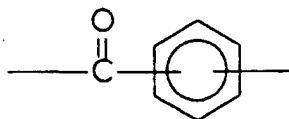
or



wherein  $x$  is an integer of 0 or 1, A is



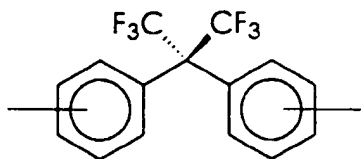




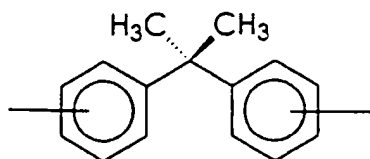
or mixtures thereof, B is



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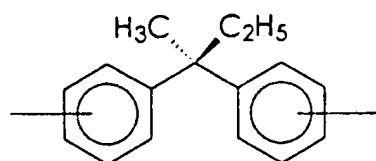


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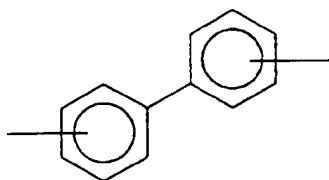
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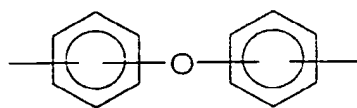
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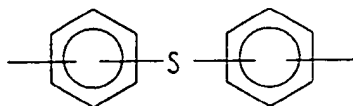


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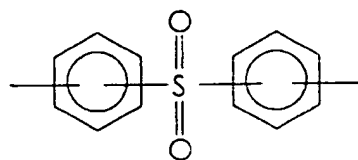
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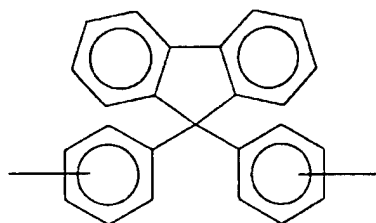
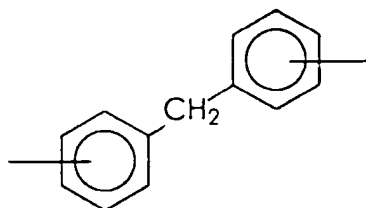
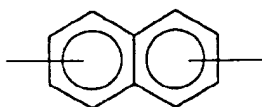
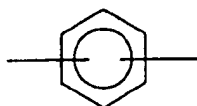
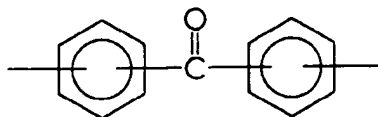


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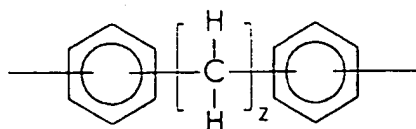


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wherein v is an integer of from 1 to about 20,



wherein z is an integer of from 2 to about 20,





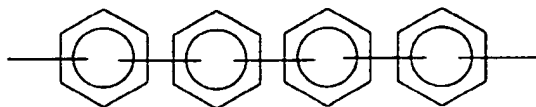
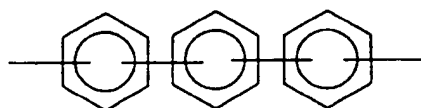
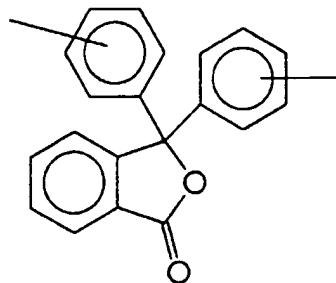
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or mixtures thereof, and  $n$  is an integer representing the number of repeating monomer units, with a functional group providing salt selected from the group consisting of an allyl alcohol salt, and an epoxy-group containing salt, thereby forming a photopatternable polymer with functional groups corresponding to the selected salt.

7. A process according to claim 6 further comprising the step of causing the polymer to become crosslinked or chain extended through the photosensitivity-imparting groups.

8. A process according to claim 7 wherein crosslinking or chain extension is effected either by heating the polymer to a temperature sufficient to enable the photosensitivity-imparting groups to form crosslinks or chain extensions in the polymer, or by exposing the polymer to actinic radiation such that the polymer in exposed areas becomes crosslinked or chain extended.

9. A process for making an ink jet printhead comprising the steps of:

(a) depositing a layer (18) comprising a polymer-containing composition according to any of claims 3 to 5 onto a lower substrate (28) in which one surface thereof has an array of heating elements (34) and addressing electrodes (33) having terminal ends (32) formed thereon;

(b) exposing the layer (18) to actinic radiation in an imagewise pattern such that the polymer in exposed areas becomes crosslinked or chain extended and the polymer in unexposed areas does not become crosslinked or chain extended, wherein the unexposed areas correspond to areas of the lower substrate (28) having thereon the heating elements (34) and the terminal ends (32) of the addressing electrodes (33);

(c) removing the polymer from the unexposed areas, thereby forming recesses in the layer (18), said recesses exposing the heating elements (34) and the terminal ends (32) of the addressing electrodes (33);

(d) providing an upper substrate (31) with a set of parallel grooves (20) for subsequent use as ink channels and a recess (24) for subsequent use as a manifold, the grooves (20) being open at one end for serving as droplet emitting nozzles; and

(e) aligning, mating, and bonding the upper (31) and lower (28) substrates together to form a printhead (10) with the grooves (20) in the upper substrate (31) being aligned with the heating elements (34) in the lower substrate (31) to form droplet emitting nozzles, thereby forming an ink jet printhead.

10. An ink jet printhead which comprises (i) an upper substrate (31) with a set of parallel grooves (20) for subsequent



use as ink channels and a recess (24) for subsequent use as a manifold, the grooves (20) being open at one end for serving as droplet emitting nozzles, (ii) a lower substrate (28) in which one surface thereof has an array of heating elements (34) and addressing electrodes (33) formed thereon, and (iii) a layer (18) deposited on the surface of the lower substrate (28) and over the heating elements (34) and addressing electrodes (33) and patterned to form recesses therethrough to expose the heating elements (34) and terminal ends (32) of the addressing electrodes (33), the upper (31) and lower (28) substrates being aligned, mated, and bonded together to form the printhead (10) with the grooves (20) in the upper substrate (31) being aligned with the heating elements (34) in the lower substrate (28) to form droplet emitting nozzles, said layer (18) comprising a polymer-containing composition according to any of claims 3 to 5.



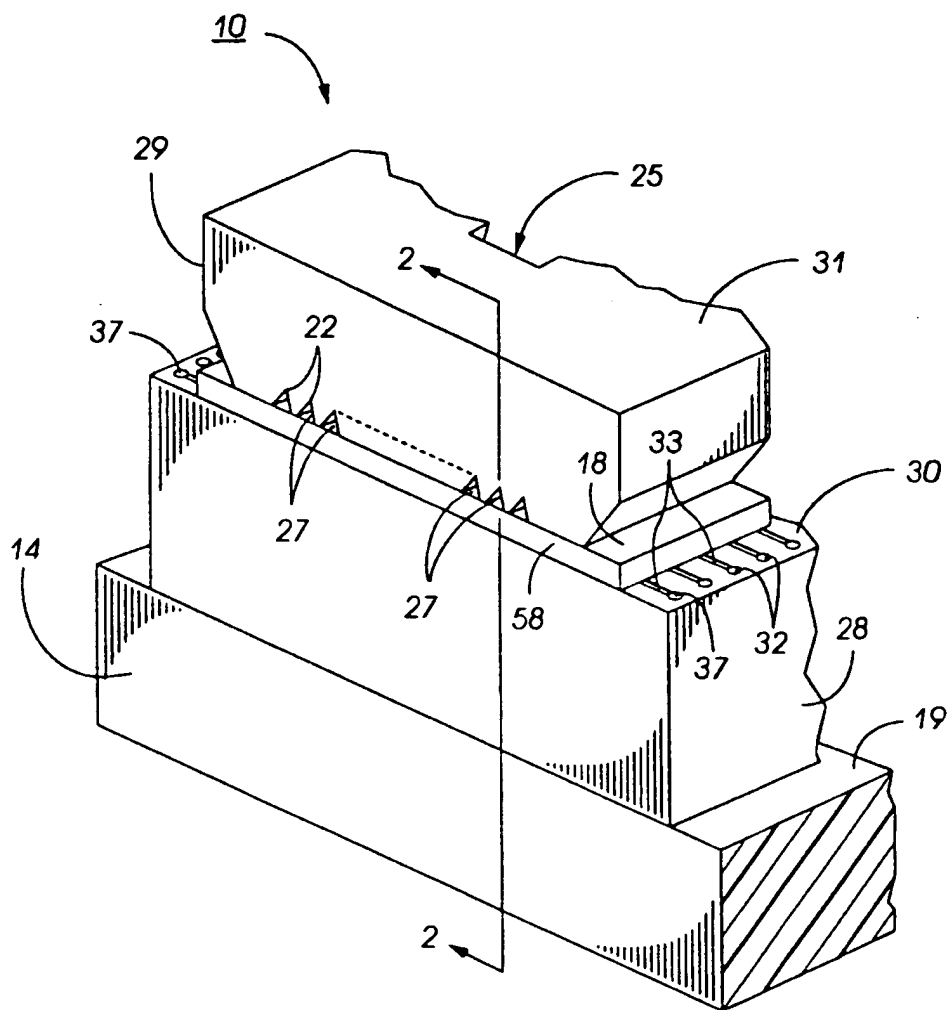
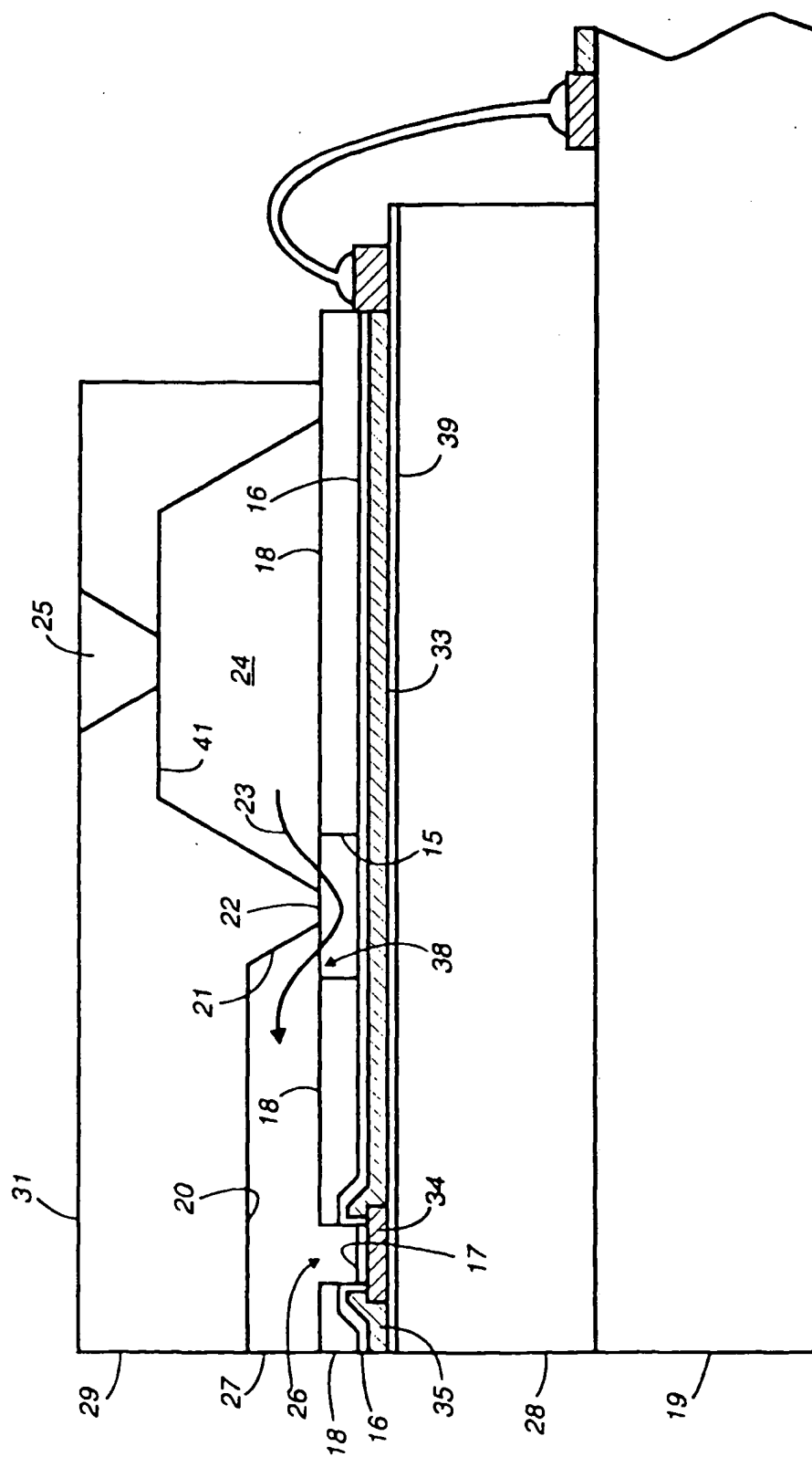


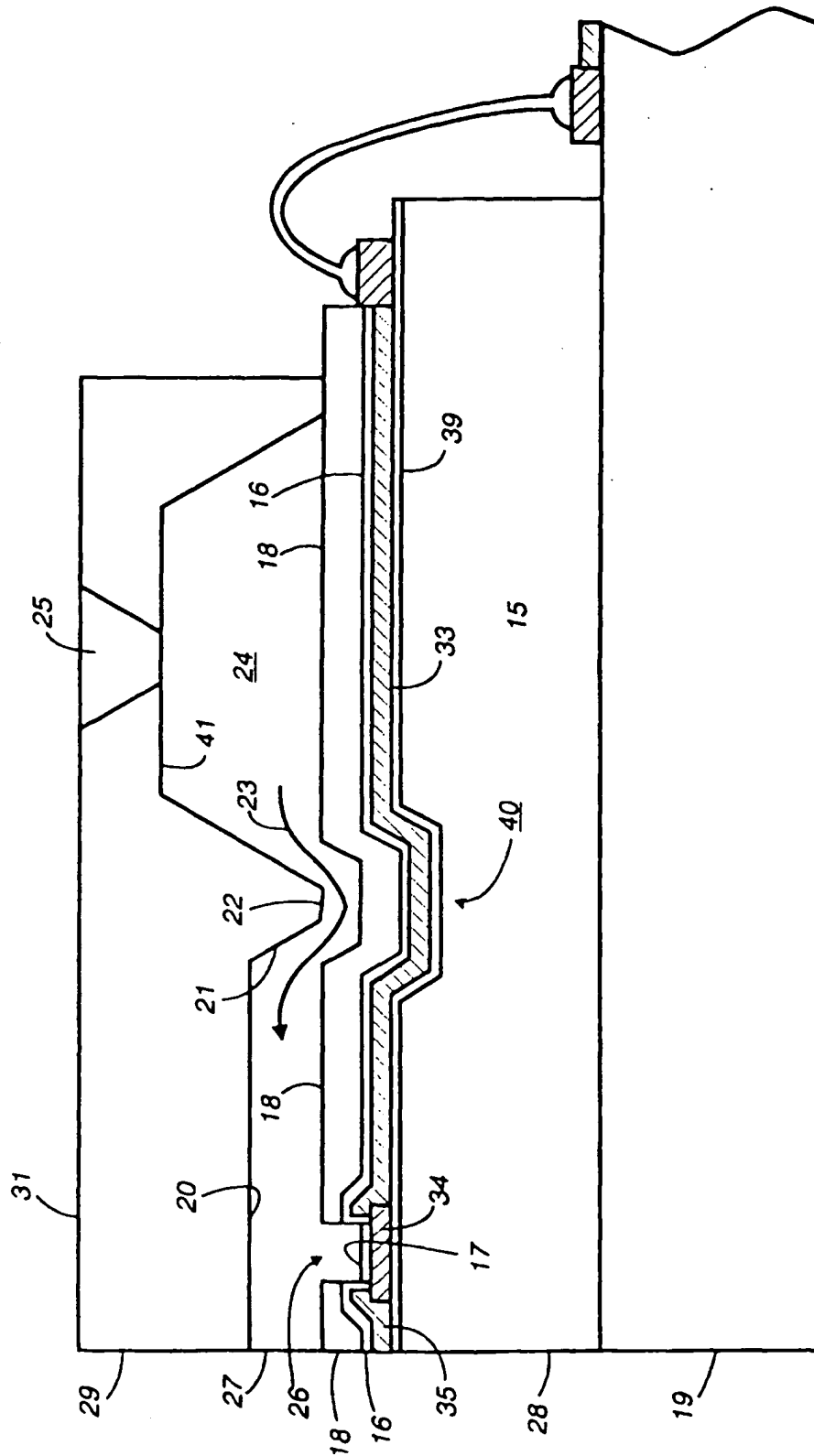
FIG. 1





**FIG. 2**





**FIG. 3**



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